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A quarterly paper devoted to the sugar interests of Hawaii and issued by the Experiment Station for circulation among the Plantations of the Hawaiian Sugar Planters' Association.

In This Issue:

Chlorotic Streak Disease of Sugar Cane:

A brief history and a description of chlorotic streak disease which occurs on several sugar cane varieties in Hawaii is presented. An account of the studies regarding its cause, an outline of investigations now being conducted and certain measures for its control are also offered.

Field studies have shown that the disease is readily transmitted with cane cuttings and this fact places the trouble in the category of systemic plant diseases. The effect of the disease on sugar yields will be determined in field tests by harvesting separate plots planted with diseased and healthy cuttings.

Nematodes Associated with Sugar Cane in Hawaii:

A brief resume of the nematode genera found in the cane fields of Hawaii, together with illustrations of some of the species.

Irrigation Measurements:

Greater accuracy in the measurement of irrigation water to small experimental plots may be had by using the Parshall Flume with six-inch throat. An arrangement by which the hook-gauge can be made portable for rapid transfer from one installation to another is described in this issue.

Twenty installations of this type at the Waipio Substation are proving satisfactory. Waimanalo Sugar Company has recently made fourteen similar installations for water measurements to level ditch plots.

A Practical Use of Cane Growth Measurements:

A comparison of the winter and summer growth of sugar cane at Kukuihaele is presented by W. C. Jennings, who makes this study by the aid of growth measurements.

Since the winter season is almost certain to be accompanied by a fair rainfall and the summer months are often subject to severe drought, it is important in that district to differentiate between the potential growth value of the different times of the year.

Cane Varieties in the Philippines:

The principal varieties in the Philippines are discussed together with some of the newer seedlings which are being tested against them.

Sugar Cane Breeding in the Philippines:

With improvements in field practices in the Philippines has come a desire for canes better able to respond to the improved conditions than the old Luzon White and Negros Purple. This has resulted in considerable interest in sugar cane breeding. A brief account is given of the past and present status of cane breeding work in the Philippines.

An Open Letter:

"An Open Letter to All Sugar Techonologists" from F. W. Zerban, general chairman of the International Society of Sugar Cane Techonologists, invites cooperation of authors of technical papers, requesting that abstracts of papers be submitted for publication in *Facts About Sugar*.

Rat Control in Hawaii:

An historical outline of pertinent work done here and elsewhere on rat control is followed by a report of the recent investigations conducted on the island of Kauai on the control of rats. Tests on 453 wild caged rats of various species are reported. Strychnine rat baits were found inefficient and distasteful to rats. Barium carbonate preparations, although highly toxic, were ignored until the rats, deprived of other food, were forced to eat them.

Thallium sulfate-treated wheat bait, of a 1 to 1,000 weight ratio, proved to be highly effective, was eaten by all rats offered such preparations and death ensued within an average of three days in all cases. Tests with field rats proved the effectiveness of this bait and it has since been adopted on those plantations which are now practicnig rat control in the cane fields. A marked reduction in numbers of rat-eaten canes coming to the mills has been effected within the first year of general use. Improved mill juices have resulted from the use of thallium sulfate-treated wheat baits.

The formula for preparation is detailed and the dangers involved in handling the drug are pointed out, as well as the precuations to be taken. The prepared rat bait is now manufactured and distributed by the Pacific Guano and Fertilizer Company, of Honolulu. The use of ready-prepared rat bait is to be preferred for

plantation use if facilities for the safe and economical preparation of thallium rat baits are lacking.

Periodic Harvesting Experiment—Waipio:

A study of the yield of cane given by the H 109 variety when planted at different periods of the year. Chemical analysis of millable cane, tops, trash and dead cane, at each period of harvest, have made possible a determination of the amounts of mineral nutrients removed from the field during the growth of the crop.

Hydrogen Ion Concentration:

A discussion of the theory involved in the use of the tenth normal calomel electrode employed in determining pH is presented from a purely chemical standpoint. The several effects of changes in temperature, pressure, and composition are treated, and equations included by which the magnitude of these effects may be calculated.

The Probable Error of Field Tests with Sugar Cane:

A statistical examination of the results of field experiments conducted by the agricultural department throughout the islands during the last ten years shows an average probable error of 6.6 per cent.

Considerable evidence is presented to show that this probable error has been influenced by the environmental variability that exists in the experimental areas. A distinct tendency toward a smaller error is noted with the higher tonnage yields, as well as on the plots which have had an ample supply of plant food nutrients, particularly nitrogen.

There is some indication that plots somewhat larger in size than those ordinarily used here, may carry a lower probable error.

Statistical Data for the Interpretation of Field Experiments:

A statistical analysis of a large amount of experimental data at Ewa Plantation Company has defined the characteristics of the normal curves of error to be expected in cane and sugar plot yields and in juices. Extreme deviations from the mean values were found to consistently lie beyond the limits of the normal curves of error concerned which prompted the development of a systematic method of plot elimination in the analysis of field experiments. Consideration has been given to the number of plot replications in their effect upon the significance of results.

Chlorotic Streak Disease of Sugar Cane

By J. P. Martin

The purpose of this article is to present briefly a history and a description of a peculiar leaf streaking disease occurring on several sugar cane varieties in Hawaii, an account of the studies to date regarding its cause, as well as an outline of investigations now being conducted and certain suggested measures for its control.

History

Raymond Conant, research agriculturist, Olaa Sugar Company, Limited, forwarded specimen material consisting of leaves of P.O.J. 36 to the Experiment Station in October, 1929. The leaves exhibited one or more long, irregular, yellowish, chlorotic streaks often extending the entire length of the leaves.

The chlorotic streaks were studied by members of the pathology department. Isolations made by C. C. Barnum from lesions on these leaves yielded several types of bacteria and fungi. Inoculations made with ten of the bacterial cultures failed to produce any symptoms similar to those occurring in the field. Histological examinations of the streaks by D. M. Weller, demonstrated that both xylem and phloem were affected and that the bundles in the advancing areas of the lesions were filled with a gum-like substance. The chlorophyll-bearing cells within the affected tissues were of a pale green or light yellowish color. Stained preparations showed bacteria (possibly of a secondary nature) to be present in the parenchyma cells surrounding the chlorophyll-bearing parenchyma and in the motor cells. A report of these investigations appears in the Experiment Station *Monthly Letter* for November, 1929.

During the month of October, 1929, inspections were made on several plantations on Hawaii to study the disease. The fields at Olaa Sugar Company were visited in company with Mr. Conant, who stated that the disease was first seen during the summer of 1927 on P.O.J. 36 plant cane and that it was again observed on the same variety of cane during the summer and fall of 1929.

A preliminary survey made by Royden Bryan and the writer, in October, 1929, showed that the disease was present on P.O.J. 36 at the following plantations: Hilo Sugar Company, Pepeekeo Sugar Company, Onomea Sugar Company, Honomu Sugar Company and Laupahoehoe Sugar Company. Other plantations on Hawaii were not visited at that time.

It was suggested to Mr. Conant during the course of this visit in October, 1929, that plantings of both diseased and healthy cuttings of P.O.J. 36 should be made in order to determine whether or not the disease is transmitted with cuttings. Mr. Conant installed an observational test to determine this point in a small plot near the mill. In addition, cuttings of P.O.J. 36 affected with the disease were selected from Field W of Olaa Sugar Company and taken to Honolulu and planted at the pathology plot, so that frequent observations could be made on the plants grown

from the diseased cuttings. In three or four months, very definite lesions typical of the disease appeared on the shoots developing from the diseased cuttings planted at Olaa Sugar Company as well as on the shoots developing from the diseased cuttings planted at the pathology plot. In both of these observational tests, the plants grown from the healthy cuttings have developed no symptoms of the disease, even after ten months. It is significant that the healthy plants did not contract the disease even though they were in contact with the diseased plants. The fact that the disease is readily transmitted by cane cuttings immediately places this disease in the category of systemic plant diseases.

A survey of the plantations on Oahu by Messrs. Barnum and Carpenter, during the early part of November, 1929, revealed the fact that the yellowish lesions of the disease were present on P.O.J. 36 at Waimanalo and one case was found on P.O.J. 36 at Waipio substation. Several cases were observed on P.O.J. 36 during August, 1930, at the Kailua substation.

Since the disease was readily transmitted with cane cuttings, it became necessary to install further observational tests to determine its effect on sugar yields. Plots planted with diseased cuttings and others with healthy cuttings are to be harvested and the quantitative data secured are to be used in determining this point. At the present writing, observational tests are under way at Olaa Sugar Company, Hilo Sugar Company and the pathology plot, Honolulu.

In the *Monthly Letter* for February, 1930, it was stated that the peculiar yellowish streaks frequently observed on leaves of P.O.J. 36 and other varieties would in the future be referred to as symptoms of "chlorotic streak disease." To date, chlorotic streak disease has been observed on the following cane varieties: P. O. J. 36, 36M, 234 and 979, U. D. 1, Yellow Caledonia, K 107, D 1135 and on a few of the newer varieties.

Description

The symptoms of chlorotic streak disease are easily recognized on the more mature leaves of an affected plant by the presence of long, irregular, yellowish, or chlorotic streaks. The streaks vary from 1/8 to 3/8 of an inch in width and in length from a fraction of an inch to the entire length of the leaf. The lesions on the leaves are somewhat irregular and wavy in outline as compared with the very definite stripes that are typical of red stripe disease. Also, the appearance of the lesions of chlorotic streak disease differs from the markings characteristic of leaf variegation in that the markings of the latter are well defined, have very sharp margins between the healthy and chlorotic areas, and usually extend onto the leaf sheath and occasionally onto the cane stalk. So far, lesions of chlorotic streak disease have not been observed on the leaf sheaths or cane stalks. The streaks are more or less parallel to the vascular bundles or veins of the leaves and, in the advanced stages, are quite conspicuous in contrast with the normal green color of the healthy portion of the leaves.

In the older streaks necrotic areas of an ash color are often present, which are separated from the healthy areas by a reddish-brown line. These necrotic areas correspond in shape to those of the large lesions and vary in length from a few inches to the entire length of the mature lesion.

Chlorotic Streak Disease
(On P. O. J. 36)

The earliest symptoms of the disease are manifested by the appearance of very indefinite yellowish streaks on the young leaves. These may occur on any portion of the leaf blade extending both upwards and downwards from the point of origin with an irregular outline, and follow the course of the vascular bundles. When one cane leaf is found affected with chlorotic streak disease it is not uncommon to find typical lesions on six or seven other leaves of the same stalk.

The leaf symptoms of chlorotic streak disease, as described above, are shown in the colored plate accompanying this article. Since the streaks are so definite on the more mature leaves, only such material should be used for positive diagnostic symptoms.

Many stalks exhibiting leaf symptoms have been cut open and examined. In a few cases a slight reddening of the vascular bundles, particularly at the nodes, has been observed. The red discoloration in the stalks has not as yet been proved to be a symptom associated with the disease. Further studies of this condition in the affected stalks are being made.

A cane disease manifesting symptoms similar to those of chlorotic streak occurs in Java and is known as The Fourth Disease; this terminology is used signifying that the trouble is the fourth vascular disease of sugar cane plants, the other three vascular diseases being Sereh, leaf-scald and gumming.

Studies of The Fourth Disease, in Java, have not disclosed an organism associated with the trouble and the cause of the disease is to date unknown. The Fourth Disease was pointed out to the writer in Java, in 1929, by Dr. G. Wilbrink, Directress of the Cheribon Sub-Experiment Station, on the cane variety P.O.J. 2878. Only an occasional diseased plant was observed and the disease was considered of minor significance.

While Dr. P. C. Bolle, pathologist of the Sugar Experiment Station, Java, was visiting the Hawaiian Islands in February, 1930, plants affected with chlorotic streak disease were called to her attention and she diagnosed the disease as The Fourth Disease.

Control Measure

As already mentioned, the disease is readily transmitted with cane cuttings and where a variety, such as P.O.J. 36, is being rapidly extended and is affected with chlorotic streak disease it seems highly advisable to recommend that only healthy cuttings be selected for planting material. To date, no serious losses have resulted but to prevent the spread of the disease and possible losses, should the disease prove to be serious, the plantations on which the disease now occurs would be justified in adopting this recommendation.

Discussion

In dealing with new sugar cane varieties we are continually confronted with new diseases in plant pathology by their appearance in the form of peculiar blemishes, markings, malformations, etc., which, in the past, have not been recorded. However, these diseases may have existed in the Territory in an inconspicuous or latent condition on the standard varieties and are only recognized on newer varieties due to the susceptibility of the latter to such maladies. Again, environ-

mental conditions may change and become extremely favorable for the development of certain cane diseases which, in the past, have been obscure or unknown.

The question naturally arises as to whether chlorotic streak disease was imported in recent years from Java through cuttings introduced from Washington, D. C.

If a systemic disease should be introduced in the cuttings of a new variety, it must be recalled that the introduced material is confined to a very small number of cuttings and that when a variety so introduced is expanded to many acres, we should expect a very large percentage of the cane so propagated to show a high degree of infection. With the disease under discussion this, however, is not the case. We find symptoms of the chlorotic streak disease in a very small percentage of any one variety that shows the disease.

This leads us to believe that the malady has been harbored in one or more of our standard varieties in an obscure form and that it now manifests itself on the more susceptible canes.

Summary

A chlorotic leaf streak now known as chlorotic streak disease, which occurs on several sugar cane varieties in Hawaii, was first called to our attention in October, 1929. According to present records, this disease has been observed but a short time in the Territory.

Laboratory studies have not established the cause of the disease. Field studies have shown that the disease is readily transmitted with cane cuttings, which fact places the disease in the category of systemic plant diseases.

The effect of the disease on sugar yields is being determined by harvesting separate plots planted with diseased and healthy cuttings.

The disease is recognized by the presence of one or more irregular, yellowish, or chlorotic streaks, especially on the older leaves. The lesions on the young leaves are somewhat indefinite. The margins of the streaks are irregular or wavy in outline as compared with the very definite outlines of the stripes characteristic of red stripe disease and leaf variegation. Frequently, the lesions may occur on from one to seven or more leaves of an individual stalk.

The leaf symptoms of chlorotic streak disease are similar to those of The Fourth Disease which occurs in Java.

Since the disease is readily transmitted with cane cuttings, it has been recommended that when a variety is being rapidly extended and is affected with chlorotic streak disease only healthy cuttings should be used for planting material.

Acknowledgment

Both Raymond Conant, research agriculturist, Olaa Sugar Company, Limited, and Royden Bryan, assistant agriculturist, Experiment Station, H. S. P. A., have aided greatly with the field studies pertaining to chlorotic streak disease and their cooperation is greatly appreciated.

Nematodes Associated with Sugar Cane in Hawaii

By Gertrude Cassidy

While a few specialists have for some time recognized the role played by nematodes in agriculture, the vast number of agriculturists have only recently become aware of the extent of their range and their economic importance.

The definitely destructive work of a few species in special crops, such as the two species of Heterodera and a few species of Tylenchus, has been observed for many years and numerous remedies suggested for their control, yet the important part played by free-living nematodes both directly and indirectly, and the fact that the damage caused by nema pests is still increasing, is only now being fully recognized.

Nematode investigations have been intermittently in progress in the Hawaiian Islands since 1905. At that time much valuable work was contributed by Dr. N. A. Cobb, who made numerous examinations of cane roots on the islands of Hawaii, Maui and Kauai, and identified the following eleven nematode genera:

1. Dorylaimus
2. Tylenchus
3. Mononchus
4. Prismatolaimus
5. Plectus
6. Monhystera
7. Anthonema
8. Diplogaster
9. Cephalobus
10. Rhabditis
11. Heterodera

To this generic list of nematodes associated with sugar cane in Hawaii may now be added the following seventeen genera:

1. Axonchium
2. Criconema } (1)
3. Xiphinema
4. Aphelenchus
5. Discolaimus } (2)
6. Isonchus
7. Actinolaimus—Not previously recorded
8. Acrobeles "
9. Bunonema "
10. Cyatholaimus "
11. Chromadora "
12. Dolichodorus "
13. Iota "

14. Ironus—Not previously recorded.
15. Rhabdolaimus "
16. Triplya "
17. Tylopharynx "

Of this additional group more than half are spear-bearing nematodes known to be plant feeders which obtain their nourishment through punctures in the root surface made by the sharp protrusile spear with which each is armed.

The importance of this exoparasitic group in Hawaii has been somewhat neglected of late, owing to the extensive plantation survey which was recently completed.

No attempt was made in this survey to include the exoparasitic forms (i.e., those which feed from the outer surface of the plant as contrasted with those which not only obtain nourishment from the plant but actually inhabit the internal root structures besides), as the vastness of their numbers precluded investigation over so great an area. (All plantations of Oahu, Maui, Kauai and Hawaii were included in the nematode survey.)

The importance of these exoparasitic forms has not, however, been forgotten and the work of identification is at present in progress.

The economic importance of these exoparasitic nematodes has long been recognized, though little or no mention has been made hitherto in these pages. The following extract gives a general indication of the importance of this group from the viewpoint of the agriculturist (3):

In recent years the study of free-living nemas has been greatly increased, and as a result the problems connected with nema pests have acquired a new aspect. . . . Today we know that soil nematodes play a very important role.

1. As consumers and destroyers of our crops—often destroying whole fields, but much oftener decreasing their yield in a less perceptible degree.

2. As consumers of, and as important workers in the distribution of the bacterial flora of the soil. Their activity is certainly not restricted to denitrifying bacteria, but extends to nitrifying forms as well. A closer study may show relations of very great importance. They carry bacteria and fungus spores everywhere. Wounds on roots or other parts of plants may very often be infected by bacterial and fungous diseases carried by these nematodes.

3. As having relationships with fungi upon which some species are known to feed. According to Zopf fungi on the other hand may use nematodes as prey.

4. As consumers of protozoa. It is known that certain fresh-water nemas feed specially on protozoa, sometimes apparently on a single species. There is a probability that some soil species may feed in a similar way, and further investigations may enable us to combat plant-injurious protozoa by the use of these nemas.

5. As furnishing a control for plant-injurious nemas. This refers to the work of predatory nemas, such as *Mononchus papillatus*, whose feeding habits have been described in this paper. There are other species of nemas with a similar significance. Here is a great field for study. Investigations should also be carried on to show more definitely the relations of these predatory forms to rotifers, oligochaetes and other soil animals.

6. As a factor in the humification of the soil, in transformation and removal of all kinds of organic matter, decaying bodies, etc.

7. As assisting in the aeration of the soil. We know how very important aeration of soil is for the growth of bacteria and all kinds of plants. Quite possibly these millions of nematodes living in the soil are highly useful aerators.

In order to solve the problem of the relation of the soil nemas to soil fertility, we require a knowledge of the nema population in the soil itself and we also need to know:

1. The composition of the nema population, the species found and their numeric representation in all kinds of soil—sandy, humus, swampy, dry-soil, hard clay, etc.

2. The horizontal and vertical distribution of nemas in all kinds of soil and the reasons for this.

3. The seasonal changes of the different species, the number of species and the number of individuals of each species.

4. The influence of habitat on the nematode population including physical, chemical and biological factors found in the habitat. The biological factors include kinds of crops and other forms of vegetation that may be present.

The working out of these problems will surely enable us to conclude why nema pests are absent in some cases, and why in apparently similar conditions they exist in such enormous numbers. A large field is thus opened up for investigations, the results of which will be of great importance to agricultural science.

Mononchus Bast. 1866, the Predacious Nematode—

Specimens of this genus were first identified around cane roots in Hawaii by Dr. N. A. Cobb, 1905.

At that time these nemas were accepted with the other ten genera as definitely established plant parasitic forms. This viewpoint has been completely reconsidered in the light of recent investigation and Mononchus is now regarded hopefully by reason of its predacious habit, as a probable means of nematode control, and an ally in the warfare waged upon all plant destructive forms.

The following extract gives an adequate and brief summary of the situation (4):

No free-living nematodes have gained more interest during recent years than those constituting the genus Mononchus; this is because the latest discoveries have led to a complete change of view concerning their economic relationships. Careful examination, here recorded, of a large number of specimens belonging to many different species of Mononchus, has fully demonstrated the predaceous character of certain common and widely spread soil-inhabiting species—which are found to feed on other small animal organisms, such as protozoa and rotifers, and, most interesting of all, on other nemas.

Economic Importance—If, as is often the case, the nemas destroyed by the mononchs are nemas injurious to agriculture then the mononchs are beneficial to man. The first definite instance of this was reported in the *Journal of Agricultural Research* in September, 1914: *Mononchus papillatus* was shown to feed upon *Tylenchus semipenetrans*, the latter a nema infesting the roots of citrus trees. Since that time the writer has observed many similar instances, fourteen of which are recorded herein.

Formerly mononchs were considered harmful to vegetation. The basis of this opinion was twofold: First, they were known to congregate about the roots and between the leafsheaths of plants, especially succulent plants, in sufficient number to justify the opinion that they would be harmful, provided they were vegetarians. Second, vegetable matter was often found in their intestines.*

More careful investigation, however, has disclosed other facts incompatible with this opinion that mononchs are harmful to vegetation. The food-habits of mononchs have now been more carefully investigated as herein recorded, and each species so studied has proved to be carnivorous. . . .

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* (Found to be due to the Mononchus sp. having devoured a parasitic prey whose intestinal contents previously contained vegetable debris.—G. C.—Author.)

As we gain familiarity with the food habits of nemas, it becomes possible on this new basis to make comparative anatomical studies, the results of which may be applied in determining the food habits of newly discovered genera and species. . . .

. . . . Picture these ferocious little mononchs engaged in a ruthless chase in the midst of stygian darkness. We may imagine them taking up the scent of the various small animals upon which they feed, among which almost anything they can lay mouth to seems not to come amiss, and pursuing them with a relentless zeal that knows no limit but repletion.

How many acres have their organic balance determined by their millions of prowling mononchs? . . .

Method of Attack—When used in conjunction with the strong dorsal tooth and the powerful lips, the rasps are remarkably efficient organs. The mononch glides up to its quarry and makes its onslaught by a quick snap of the head, throwing its jaws suddenly wide open and grappling its prey by means of the inner armature of the lips. As the jaws close in, the victim's body is jammed against the point of the dorsal tooth, as well as against the rasps and in this way is at once both punctured by the tooth and lacerated or milled by the rasps. . . .

Fig. 1. A mononch about to seize its victim. (After Cobb.)

Geographic Distribution—Variety of Habitat—Mononchs are found in all the habitable regions of the world. They inhabit the soils and fresh waters of every clime, occurring even at great depths in lakes and at very high altitudes on mountains. While we have only just begun to learn the details of their geographic distribution, it is already manifest that some species are cosmopolitan. . . . *Mononchus longicaudatus,* for instance, is known from the tropics, from temperate regions and from very cold regions and inhabit both soil and fresh

water. Another species, *Mononchs brachyurus* is known from warm springs and from cold Alpine lakes.

Both of the two species cited (*M. longicaudatus* and *M. brachyurus*) together with several other species are readily found associated with sugar cane in Hawaii. Recent experimental work has gone to prove the unquestionable value of members of this genus in reducing the population of plant injurious forms. *Mononchus papillatus* (also present in Hawaii) has been observed to devour as many as eighty-three Heterodera in one day, and it has been definitely proved that members of this genus are not vegetarians and are therefore beneficial to the welfare of the crop and industry.

Considerable discussion has been stimulated during the recent investigations as to the exact amount of damage which can be attributed to nematodes infesting cane. With a view to demonstrating this to the satisfaction of outside workers, the accompanying chart was made to demonstrate the numerical infestation of cane root per linear centimeter of root. The stool selected was one of hundreds examined in the course of the nematode survey. This stool was listed under the heading of "Moderate Infestation with *Tylenchus similis*" (a standardization determined by an estimated 50 per cent root infestation). One linear centimeter of infested root was found to contain 600 worm forms (*Tylenchus similis*) and 300 eggs (*Tylenchus similis*).

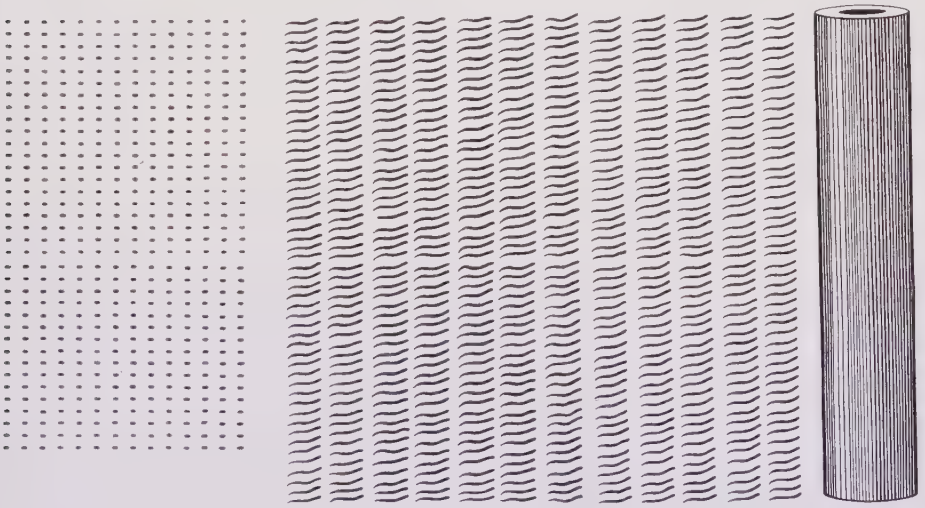

Fig. 2. A representation of the actual count of nematodes and eggs (*Tylenchus similis*) found in 1 cm. of infested cane root (Hawaii, 1930). x 6.4.

The diagrammatic representation presents the root and the infesting nematodes in their correct proportions. Further comment is perhaps unnecessary as the individual may judge for himself the probable proportions of a severe infestation. Extensive collections of exoparasitic cane nematodes have been made during the past few months and much valuable material prepared for identification.

To reiterate the difficulties attendant upon this branch of the work is unneces-

sary as allusion to it may be found in practically every paper ever published in connection with the subject.

Valuable information generously imparted by other workers in the United States and in Europe as to additional equipment and elaborated technique has facilitated the work appreciably and already a certain amount of identifications have been completed. The recent collections prove the soils of our cane fields to possess a large and varied population of nematode genera. The majority of these have not previously been recorded for Hawaii and include many new and little known species.

Tylopharynx annulatus Cassidy (in. litt.). A new species of a genus not hitherto recognized in Hawaii. This nematode is possessed of a strong, highly chitinized tripartite spear and was found very abundantly around the roots of sugar cane growing upon land previously in rice. In many ways it resembles the endoparasitic *Tylenchus similis* but as yet this genus (*Tylopharynx*) has not been observed within the internal root structures of the cane. (See Fig. 3.)

Tylenchus spiralis Cassidy (in. litt.). A new species closely resembling *Tylenchus dihystera* Cobb commonly found associated with the roots of sugar cane, pineapple, banana, rice and coffee in Hawaii. This species is distributed throughout the islands and is apparently uninfluenced by altitude or by varied soil environment. It has been found in sandy soils at sea level, in the colloidal soils of rice lands and in forest soils rich in humus at an elevation of more than 1000 feet. (See Fig. 4.)

Actinolaimus elaboratus (Cobb) Cassidy (in litt.). An unusually large sized species, originally found by Cobb, associated with diseased cane in Kohala and described by him in 1905 under the genus Dorylaimus. No diagrammatic representation of this species has previously been published. The highly complex pharyngeal cavity containing the strongly chitinized protrusile spear is worthy of attention. *Actinolaimus elaboratus* is an exoparasite believed to puncture the root surface and so obtain nourishment by extracting the root juices by means of its powerful hollow spear. (See Fig. 5.)

This genus is found in Hawaii commonly associated with the roots of sugar cane and of coffee. It has been demonstrated at high elevations (over 1000 feet) and also in lowland areas near sea level in various types of soil.

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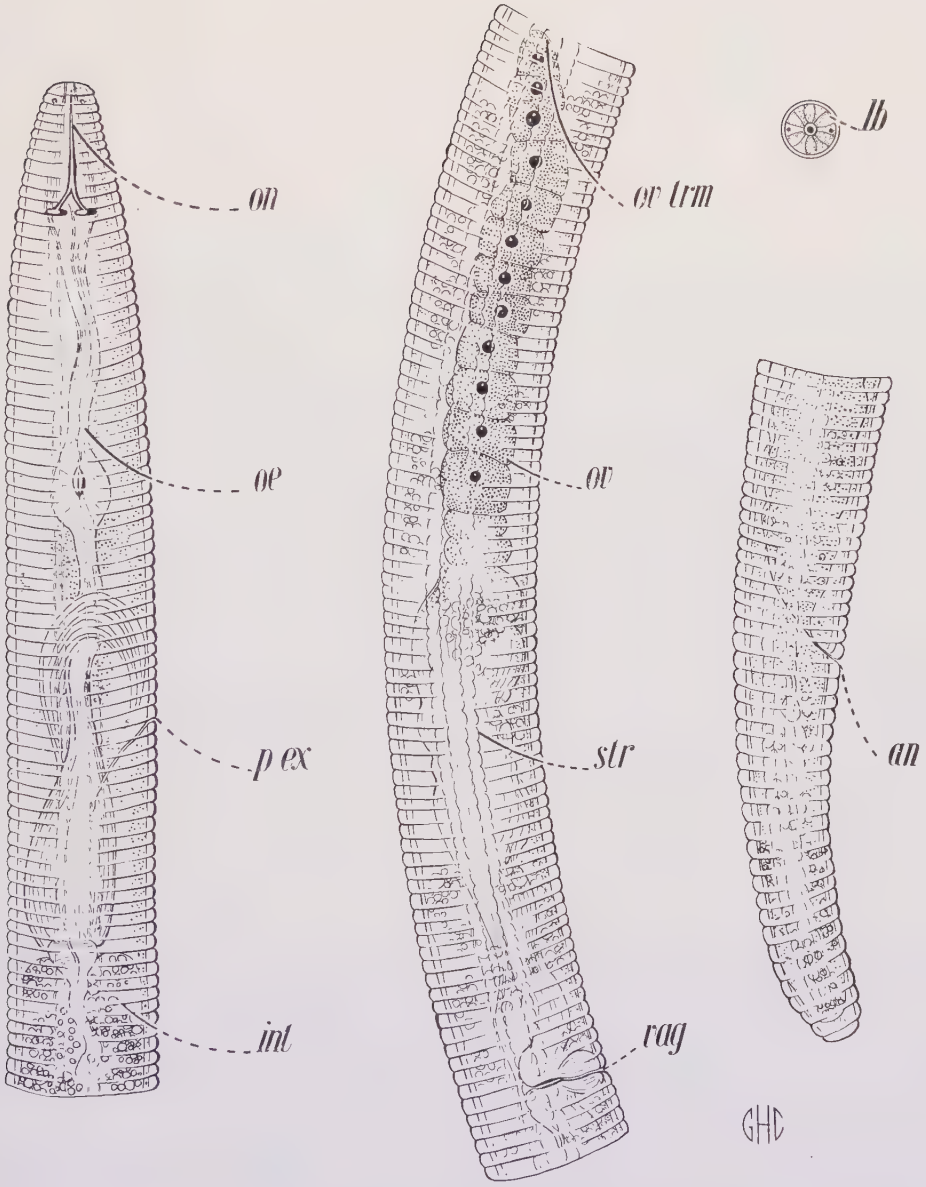

Fig. 3. *Tylopharynx annulatus* x 814.

Adult female measuring .65 mm. (body sections and front view of head).

an—anus; *int*—intestine; *lb*—lip; *oe*—oesophagus; *on*—spear; *ov*—ovary; *ov trm*—termination of ovarian tube; *p ex*—excretory pore; *str*—longitudinal striations; *vag*—vagina.

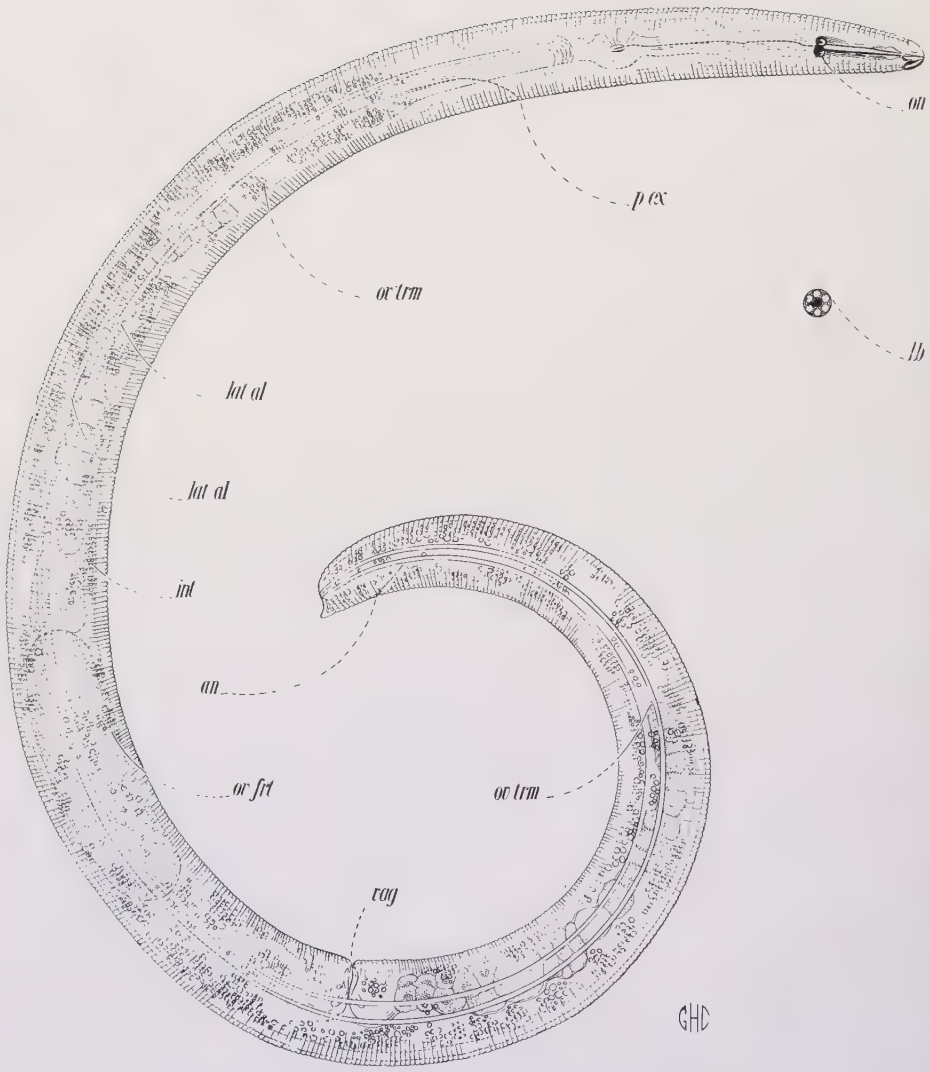

Fig. 4. *Tylenchus spiralis* x 470

Adult female measuring .65 mm. Inset—front view of head.

an —anus; *int*—intestine; *lat al*—lateral ala; *lb*—lip; *p ex*—excretory pore; *on*—spear; *ov frt*—fertilized egg; *ov trm*—termination of the ovary; *vag*—vagina.

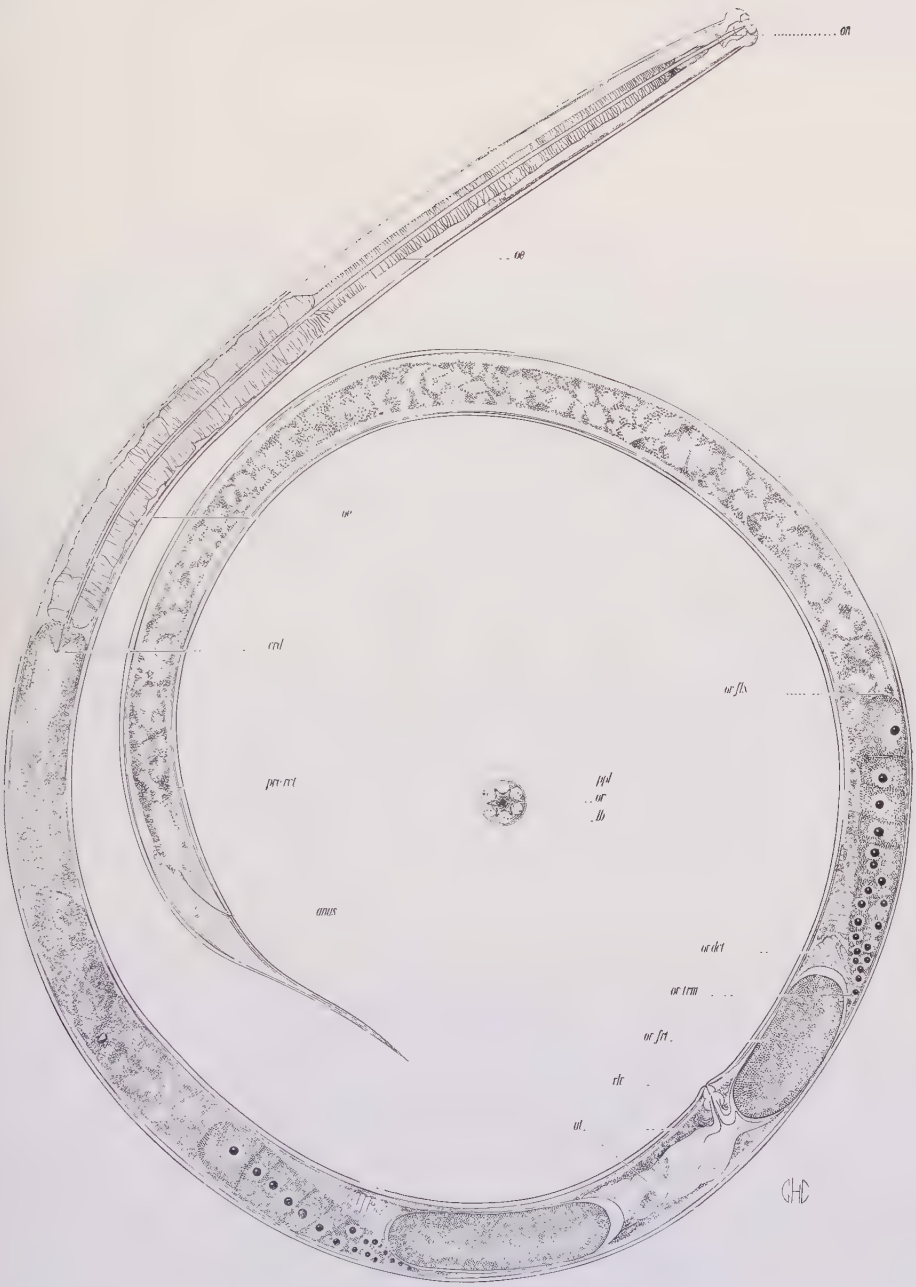

Fig. 5. *Actinolaimus elaboratus* (Cobb) x 284.

Adult female measuring 1.7 mm. The central figure represents the front view of the head.

anus—anus; *crd*—cardia; *lb*—lip; *oe*—oesophagus; *on*—spear; *or*—mouth; *ov det*—oviduct; *ov flx*—ovarian flexure; *ov frt*—fertilized egg; *ov trm*—termination of ovarian tube; *ppl*—papilla; *pre rct*—pre-rectum; *ut*—uterus; *vlv*—vulva.

Measurement of Irrigation Water to Small Plots at the Waipio Substation

By H. R. Shaw

Detailed studies of certain relationships of irrigation water to the cane plant have been in progress for several years at the Waipio Substation. Due to the limited area available for irrigation investigations and to the advisability of lessening errors caused by soil variation, unequal water distribution, and seepage losses in level ditches, attempts have been made to measure the water at the junction of the level ditch and watercourse. Plots to which irrigation water is measured vary in size from 0.1 to 0.2 acre.

Difficulties have been encountered in perfecting a type of measuring device which would be satisfactory under such conditions. Portable steel weirs set in the level ditch were abandoned because of the seepage of water around the facings and because of the difficulty in setting the weir plumb and vertical in the level ditch. Concrete installations of submerged orifices used with Great Western meters have also proved rather unsatisfactory. Inherent disadvantages of the sub-

Six-inch Parshall Flume with hook gauge in place.

merged orifice as a type of control and of the Great Western meter as a type of recorder were augmented by frequent clogging of the orifice and meter propeller with trash and algae.

As the basic results of the experiments are dependent on the accuracy of the water measurement, it was necessary to devise a type of measurement which would be as accurate as possible without disproportionate costs in labor and material.

The Parshall (Venturi) Measuring Flume, constructed according to specifications given in Bulletin 336 of the Colorado Experiment Station, was adopted as the most accurate and satisfactory means of water measurement. A steel form was constructed by means of which concrete Parshall installations with 6-inch throats could be made. The crest of the flume was set 6 inches above the level of the watercourse directly below the proposed installation in order to insure free flow discharge. The structural strength of the flume is provided by a backfill of

Hook gauge mount and carrier.

field stone. The concrete (1:3:6 mix of cement, beach sand, and rock sand) serves as a mortar and as a smooth facing of the flume sides. The total cost of the flume in place is estimated at approximately $10.

The actual measurement of water is made by means of a hook gauge which can be moved from one installation to another. A stilling well, 8 inches in diameter, is cast at the same time that the walls of the flume are set. The bottom of

the stilling well is 6 inches below the level of the flume floor so that silting space is provided. A one-half inch pipe leads from the flume wall, at a point two-thirds of the distance from the crest to the entrance and just above the floor level, to the stilling well. An upright, 4″ x 4″ x 24″ is set vertically in the face of the stilling well wall. In the upright, a 2″ x 2″ groove is cut with the base of the groove level with the floor of the flume. The hook gauge is mounted on a 4″ x 4″ x 24″ which is cut to 2″ x 2″ about 6 inches from the top. The 2″ x 2″ portion of the hook gauge mount slides into the groove on the carrier, the upper portion of the mount resting firmly on the top of the carrier, and the tip of the hook on a level with the carrier base. The gauge may be checked readily and frequently with a level by reading the rod when placed on the floor of the flume,

Reading hook gauge in place.

then resting the rod lightly on the tip of the hook when the gauge vernier is at zero. The gauge screw is adjusted until the rod reading is the same as when on the flume floor. The correction may then be read directly from the gauge vernier.

It is necessary, of course, to have an operator of the hook gauge constantly present during the irrigation. Under present conditions at Waipio, from one to two minutes is required for the irrigator to complete each line. There is comparatively little fluctuation in head after irrigation to the plot has started. The gauge operator determines the head over the flume every minute by adjusting the

gauge screw until the tip of the hook makes a "pimple" on the water of the stilling pond, and then reading the head directly from the vernier. He also records the time required by the irrigator to fill the furrow with water. If more than one minute is required to fill the furrow, the average discharge is taken from a series of readings at one-minute intervals. The figures are recorded in the table shown below, and the discharge in cubic feet for each line is determined from prepared tables showing the relation of head to discharge, and of discharge and time to total amount. The sum of cubic feet per line for the entire plot can be easily converted to an application figure of Gallons or Acre Inches per Acre.

This method of water measurement to small plots probably requires too much detail and attention to be employed in the average plantation experimentation. Where the success of the experiment depends upon the accuracy of water measurement, however, it is felt that this method will give greater satisfaction than any so far developed.

WAIPIO SUBSTATION
Irrigation Data
Parshall Flume Measurement

Experiment F — Date.....
Plot No. 6 — Irrigator.....
Time Started: 6:04
Time Finished: .....

Hour	Min.	Sec.	C.F.S.	Head	Cu. Ft.
6:04	1	60	.20	.23	12.00
6:05	2	120	.20	.23	27.60
6:07	1	60	.22	.24	14.44
6:08	2	120	.22	.24	28.80
6:10	2	120	.22	.24	28.80
6:12	1	60	.23	.25	15.00
6:13	2	120	.23	.25	30.00
6:15					

Winter Growth at Kukuihaele

By W. C. Jennings

This is the first of a series of papers dealing with cane growth studies conducted on the Kukuihaele division of Honokaa Sugar Company during the past five years.

This paper is concerned principally with emphasizing the large percentage of our total growth which is secured during the winter months. Climatic conditions and the elevations at which cane is grown at Kukuihaele are similar, in a large degree, to most of Hamakua and also the Kohala district. Later papers will deal with data collected during 1923 and 1924 in the Kohala district, which support this supposition that conditions are similar.

The average monthly cane growth at Kukuihaele from November 1, 1924, to July 31, 1930, is tabulated below. These averages are the result of from 800 to 1400 measurements taken monthly at from 150 to 1650 feet elevation and at all times as nearly as possible evenly divided between young cane, or first season growth, and cane which is making second season growth.

TABLE I

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1924											5.13	3.81
1925	2.81	3.90	4.41	5.49	7.21	6.51	7.83	7.22	9.71	7.06	5.34	2.67
1926	2.54	3.34	5.23	6.08	6.85	5.89	4.91	7.93	8.75	7.80	8.82	3.92
1927	2.73	3.03	3.56	8.27	5.53	5.07	7.32	8.77	7.71	7.62	5.92	4.65
1928	3.43	2.89	3.83	6.78	8.37	6.94	9.35	8.55	8.40	4.35	5.26	3.53
1929	4.05	5.13	5.19	7.89	9.53	4.58	5.08	6.92	3.99	2.43	5.17	3.52
1930	4.61	6.56	6.34	6.82	5.38	7.91	6.25					

Table II gives the monthly rainfall averages over the same period.

TABLE II

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1924											7.79	.72
1925	7.23	1.18	9.44	6.60	3.61	2.52	1.50	7.82	2.15	2.13	3.43	.46
1926	1.21	2.66	1.41	8.31	1.53	4.69	2.29	5.01	2.69	5.74	5.23	1.99
1927	10.62	2.28	2.10	11.43	.86	1.08	6.99	3.20	3.78	2.33	8.14	7.93
1928	3.73	3.05	3.78	1.75	4.57	2.00	5.83	2.51	4.29	1.32	6.56	7.79
1929	12.03	14.98	10.31	8.29	2.75	1.13	2.50	6.27	.34	.48	13.65	17.54
1930	6.50	7.20	7.79	16.93	4.14	6.08	3.94					

For a number of years W. P. Naquin, for the purpose of comparing the annual winter and summer rainfall, has been terming the period from November 1 to April 30, winter, and May 1 to October 30, summer. This segregation of the months has been used in compiling the following data:

The data contained in Tables I and II are expressed graphically in Figs. 1, 2 and 3. In these three graphs the solid line is the growth curve, while rainfall is shown by the stepped or upright lines and all values are expressed in inches.

These data are complicated somewhat by the measurements taken on 250 acres of plant Uba during 1927 and 1928. This Uba was planted on hilltops that had been thrown out of cultivation several years before as having too poor soil for growing cane. Uba, which is slow growing at best as plant cane, under these conditions made very slow growth and somewhat depressed the curve for the years 1927 and 1928. The 1929 depression is due to the dry summer of 1929, which is brought out very clearly in Fig. 3.

To show in more detail the relation between rainfall and cane growth, Tables III and IV follow. Table III gives the rainfall for the years 1924 to 1929 with the five-year average for each month in inches and also the average percentage values for each month. Table IV gives the cane growth for the same period and the average monthly values in inches and percentage.

TABLE III

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1925	7.23	1.18	9.44	6.60	3.61	2.52	1.50	7.82	2.15	2.13	3.42	.46
1926	1.21	2.66	1.41	8.31	1.53	4.69	2.29	5.01	2.69	5.74	5.23	1.99
1927	10.62	2.28	2.10	11.43	.86	1.08	6.99	3.20	3.78	2.33	8.14	7.93
1928	3.73	3.05	3.78	1.75	4.57	2.00	5.83	2.51	4.29	1.33	6.56	7.79
1929	12.03	14.98	10.31	8.29	2.75	1.13	2.50	6.27	.34	.48	13.65	17.54
Total	34.82	24.15	27.04	36.38	13.32	11.42	19.11	24.81	13.25	12.09	37.00	35.71
Average	6.96	4.83	5.41	7.27	2.66	2.28	3.82	4.96	2.65	2.40	7.40	7.14
% value	12.04	8.36	9.41	12.58	4.60	3.95	6.61	8.58	4.58	4.15	12.79	12.35

TABLE IV

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1925	2.81	3.90	4.41	5.49	7.21	6.51	7.83	7.22	9.71	7.06	5.34	2.67
1926	2.54	3.34	5.23	6.08	6.85	5.89	4.91	7.93	8.75	7.80	8.82	3.92
1927	2.73	3.03	3.56	8.27	5.53	5.07	7.32	8.77	7.71	7.62	5.92	4.65
1928	3.43	2.89	3.83	6.78	8.37	6.94	9.35	8.55	8.40	4.35	5.26	3.53
1929	4.05	5.13	5.19	7.89	9.53	4.58	5.02	6.92	3.99	2.43	5.17	3.52
Total	15.56	18.29	22.22	34.51	37.49	28.99	34.43	39.39	38.56	29.26	30.51	18.29
Average	3.11	3.66	4.44	6.90	7.49	5.80	6.89	7.88	7.71	5.85	6.10	3.66
% value	4.49	5.26	6.38	9.93	10.78	8.35	9.9	11.34	11.10	8.42	8.78	5.27

Fig. 6 shows how closely the monthly averages for the past five years check with the averages of the past twenty-four years. This figure also shows that the months of June, July, September and October are consistently dry and that we can be fairly certain of getting good rains during August.

These tables and graphs show roughly what every plantation knows—that there is but little relation between winter rainfall and cane growth and a positive correlation between the amount of summer rainfall and cane growth. However, this paper is not primarily concerned with the factors controlling cane growth, else temperature and wind velocity data would also be included. These data have been arranged in this manner with the idea of drawing attention to the large percentage of our total cane growth which is secured during the winter months.

These figures support our belief that it is possible to increase our winter cane growth and that the greater part of any future increase in yields must come through agriculture that is based on the theory that every advantage must be taken of winter rains.

Field men in the Hamakua and Kohala districts are particularly apt to minimize the value of March and April as growing months. Cane that has lost color, in December and January has often started up rapid growth in March and April which at times is not visually evident until June or later. On the other hand, cane that has a good green color in June or July may have already slowed up the rate of growth due to lack of moisture. Color and general appearance alone are of no immediate value in determining the condition and rate of growth or the growth value of a given period. In the Hamakua district where cane growth is comparatively slow under average climatic conditions, the dependence on color or general appearance as a criterion of the condition of a field is apt to leave one at all times from four to ten weeks behind what is actually occurring. Our growth measurements show conclusively that by depending on visual evidence alone we would, most of the time, be several weeks late in determining what the rate of growth has been.

The management of this plantation believes that taking advantage of winter growth conditions has been a large factor in the constant gains in yield per acre which have been secured here over the period which these data cover. This has been done by planning crop rotation, fertilization and all agricultural practices to take advantage of the almost certain optimum moisture conditions of the greater part of the winter months. Temperature is, of course, the controlling factor during the winter months, but it is a comparatively constant or stable factor, while rainfall, which controls the amount of summer growth, is so uncertain a factor that we cannot hope to carry any crop through the summer months without one or more setbacks from lack of moisture.

Table V and Fig. 7 give the percentage of summer and winter growth for the years 1925 to 1929.

TABLE V

Year	Total Growth	Winter		Summer	
		Inches	%	Inches	%
1925.....	70.4	25.55	35.9	44.95	64.1
1926.....	67.33	25.20	37.5	42.13	62.5
1827.....	72.35	30.33	41.9	42.02	58.1
1928.....	73.46	27.50	37.4	45.96	62.6
1929.....	63.52	31.05	48.9	32.47	51.1

Summary

1. The summarization of five years of growth measurement data at Kukuihaele indicates that the rate of cane growth or the growth value of a given period cannot be accurately determined by observing the color and general appearance alone and that without growth measurements such observations are apt to be misleading.

2. During the five-year period—1925 to 1929—40.12% of the annual cane growth at Kukuihaele was secured during the period November 1 to April 30.

3. Winter growth at Honokaa Sugar Company has been increased by taking advantage of the optimum moisture conditions of most of the winter months, admitting, however, that temperature is the inhibiting growth factor during winter months.

4. Comparing the five-year averages of 1925 to 1929 with the twenty-four-year averages of 1906 to 1929 shows that June, July, September and October are consistently dry, but that we can look for good rains during August.

5. Dry weather in June, July, September and October is more apt to limit the possible effects of future improvements in our agriculture than will the low temperatures of the winter months.

6. Winter growth factors are fairly stable when compared with the variable inhibiting factor of summer growth which is, of course, lack of moisture caused by wide fluctuations in monthly rainfall and inevitable periods of drought.

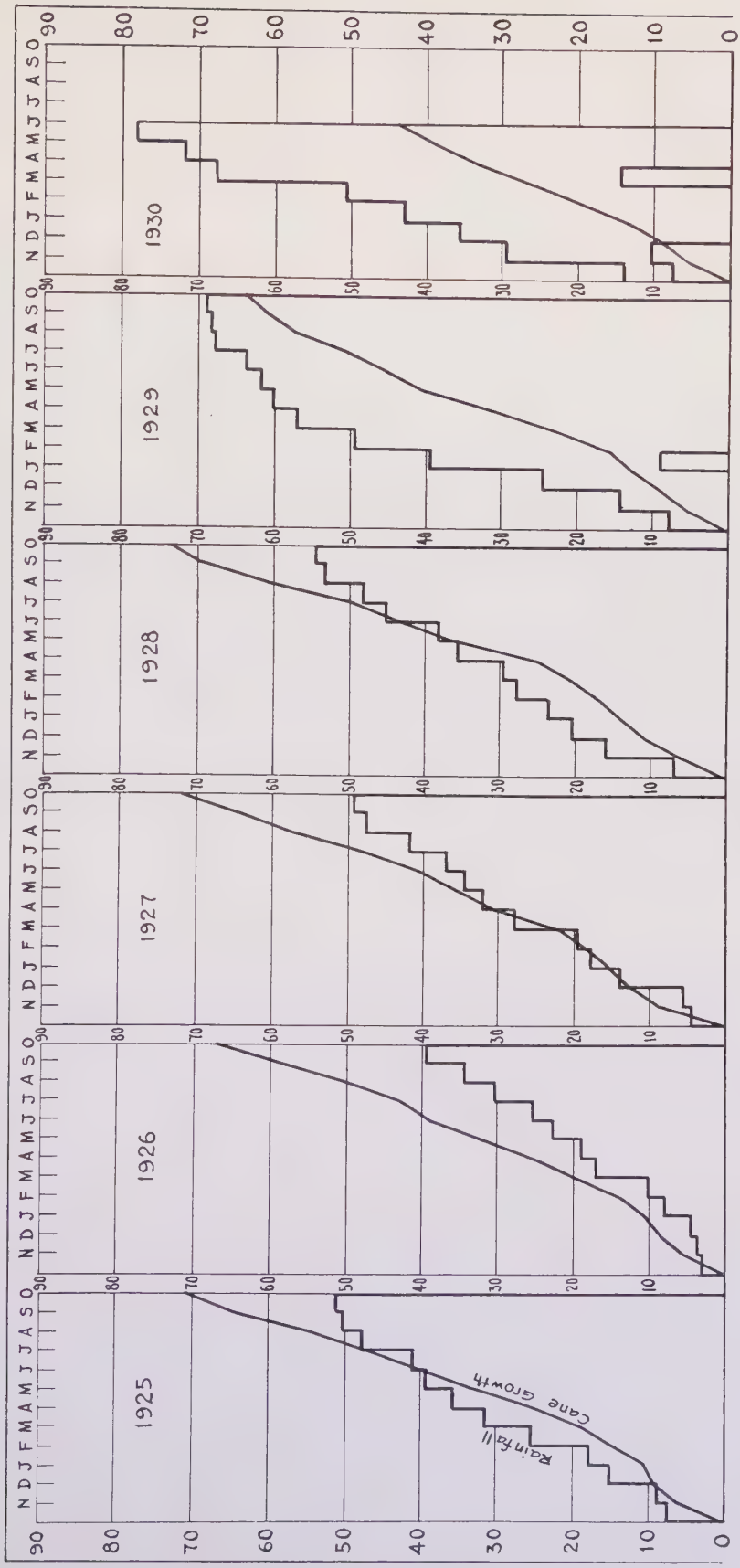
Rainfall and Cane Growth in Inches
0
10
20
30
40
50
60
70
80
90
N D J F M A M J J A S O
1925
1926
1927
1928
1929
1930
Rainfall
Cane Growth

Fig. 1

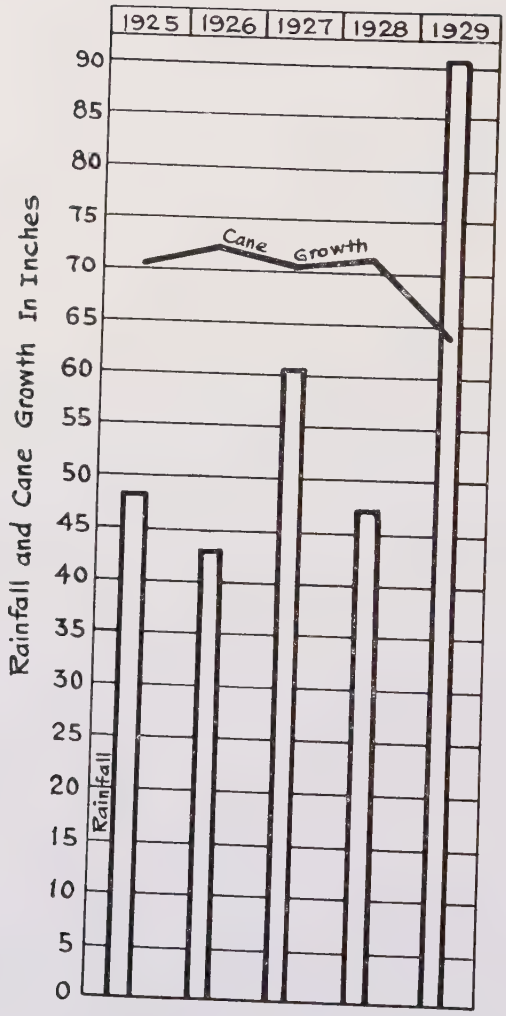
1925
1926
1927
1928
1929
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
Rainfall and Cane Growth In Inches
Cane Growth
Rainfall

Fig. 2

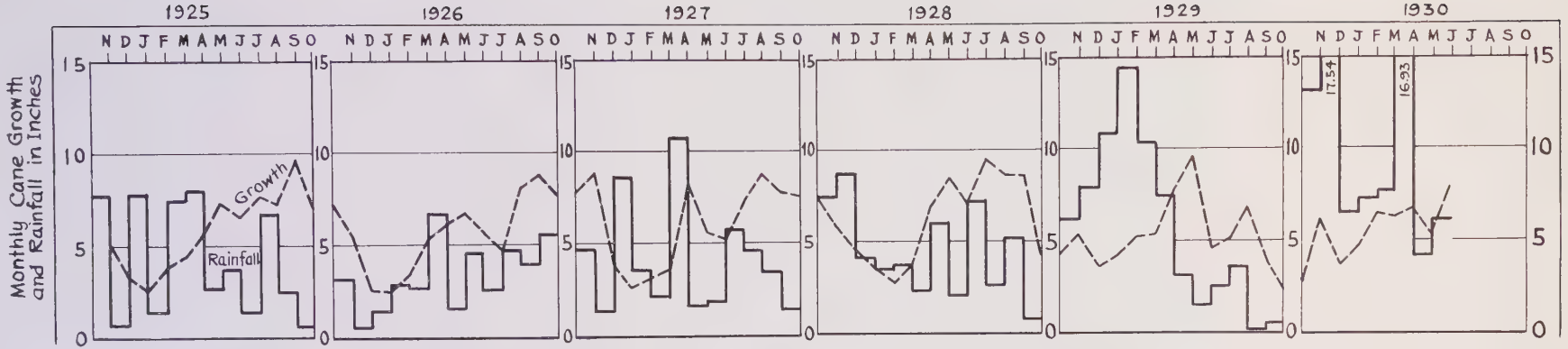
1925
1926
1927
1928
1929
1930
N D J F M A M J J A S O
15
10
5
0
Monthly Cane Growth and Rainfall in Inches
Growth
Rainfall
17.54
16.93

Fig. 3

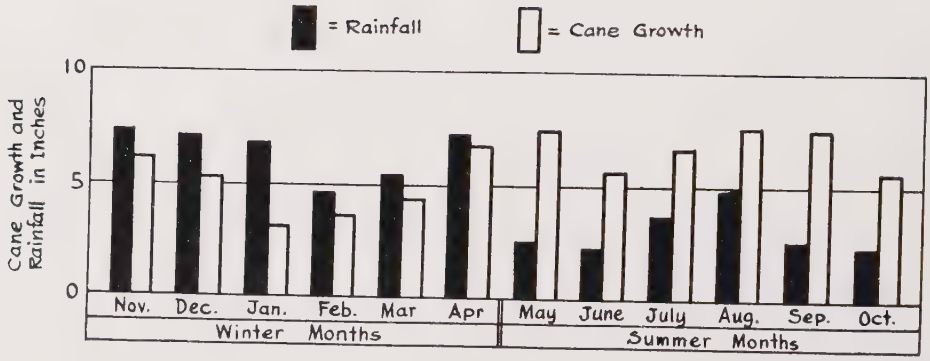
= Rainfall
= Cane Growth
Cane Growth and Rainfall in Inches
10
5
0
Nov. Dec. Jan. Feb. Mar Apr
May June July Aug. Sep. Oct.
Winter Months
Summer Months

Fig. 4

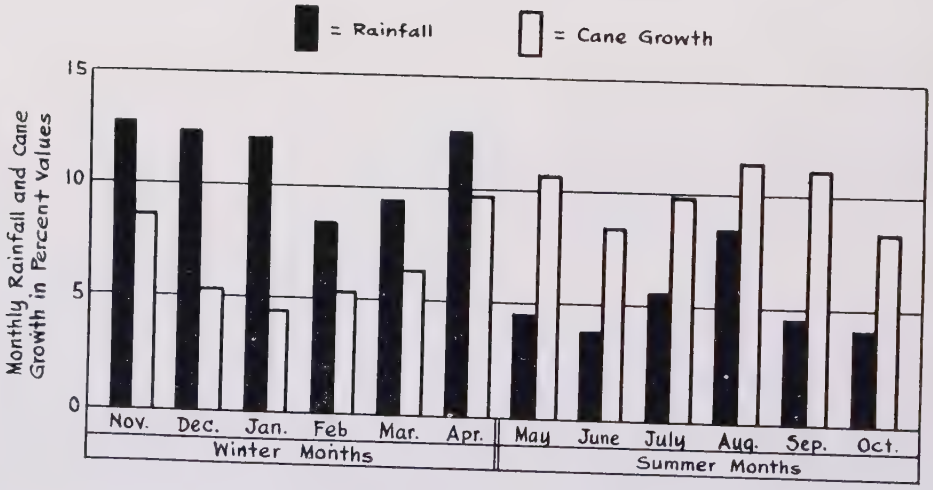
= Rainfall
= Cane Growth
Monthly Rainfall and Cane Growth in Percent Values
15
10
5
0
Nov. Dec. Jan. Feb Mar. Apr.
May June July Aug. Sep. Oct.
Winter Months
Summer Months

Fig. 5

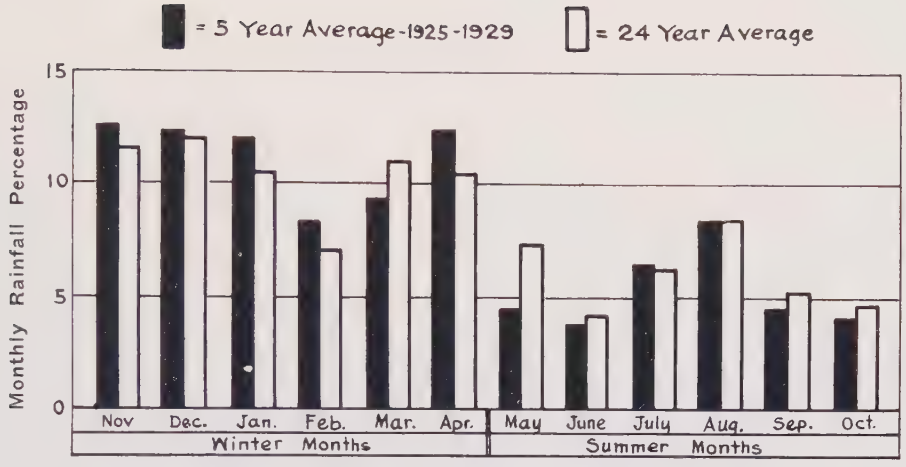
= 5 Year Average-1925-1929
= 24 Year Average
Monthly Rainfall Percentage
15
10
5
0
Nov
Dec.
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sep.
Oct.
Winter Months
Summer Months

Fig. 6

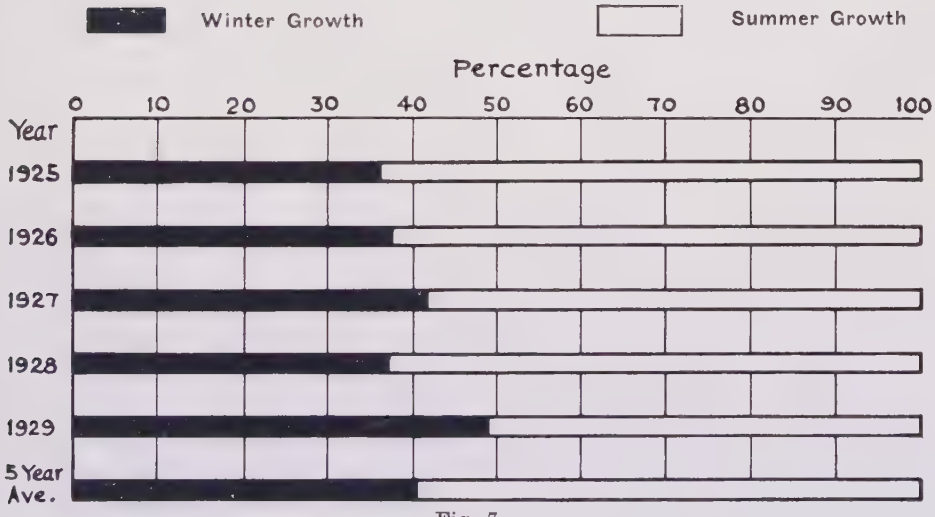
Winter Growth
Summer Growth
Percentage
0
10
20
30
40
50
60
70
80
90
100
Year
1925
1926
1927
1928
1929
5 Year Ave.

Fig. 7

Cane Varieties in the Philippines

By A. J. Mangelsdorf

Negros

Negros produces about 70 per cent of the Philippine sugar crop. A dense population, which means an abundance of labor, and a fairly uniform rainfall throughout the year are the principal factors responsible for the extensive sugar industry of this island.

Formerly Negros Purple was the only variety grown. It still occupies about four-fifths of the total area.* This variety has excellent juices, is dependable under a wide variety of conditions, and is a cheap cane to cultivate. It tassels, but not excessively and we were told that it "germinates rather poorly, but not so poorly as H 109." It is an excellent ratooner. It is, however, rather susceptible to leaf scald, mosaic, Fiji disease and smut. It also suffers from excessive or deficient moisture and is not well suited to adverse conditions.

Negros Purple and Cebu Purple are local names for one and the same cane, according to the general opinion of those familiar with them.

Badila occupies most of the remaining acreage of Negros and has been rapidly gaining in favor. It has been tried in comparison with Negros Purple in a number of yield tests. In most of these it has proved superior to the latter. Badila is very resistant to Fiji disease.

H 109, D. I. 52 and P.O.J. 2878 together occupy the remaining acreage. D. I. 52 is doing well and is attracting some attention. There is some question as to its susceptibility to Fiji disease. It is not a particularly vigorous cane and it will be surprising if it should be able to compete with the sturdier varieties now under trial.

P.O.J. 2878 is attracting a great deal of attention in Negros. Atherton Lee, director of research for the Philippine Sugar Association, has reported the figures from some ten variety experiments in which P.O.J. 2878 was tested against Negros Purple, D. I. 52, Badila and New Guinea 24A, with the following results.

P.O.J. 2878 outyielded Negros Purple in each of the nine tests in which they were compared.

P.O.J. 2878 outyielded D. I. 52 in six out of eight tests. Its failure to do so in the other two tests is attributed to poor stands.

P.O.J. 2878 outyielded Badila in seven out of eight tests.

P.O.J. 2878 outyielded New Guinea 24A in each of the five tests in which they were compared.

* I am indebted to Atherton Lee, director of Research for the Philippine Sugar Association, for the estimates of acreages occupied by the different varieties, and for other information and assistance.

These experiments consisted of ten one-eighth-acre replications of each of the varieties tested. The figures may therefore be taken as quite reliable for the conditions under which the respective tests were carried out.

According to a report from the Philippine Sugar Association, at least thirty experiments comparing P.O.J. 2878 with other varieties will be harvested in Negros during the coming crop. If these bear out the results from this year's tests, we may expect to see P.O.J. 2878 taking its place as the leading variety in Negros within a very few years.

The following table gives the 1929-1930 variety census for the Hawaiian-Philippine Company. While not quite typical of the island as a whole it is nevertheless of interest.

Varieties	Hectares	Per Cent
Negros Purple	4709.02	55.60
Badila	3347.30	39.52
D. I. 52	172.69	2.04
New Guinea 24-A	113.27	1.34
New Guinea 24	27.62	.33
S. W. 3	11.21	.13
Java 247	11.71	.14
Hambledon	23.26	.27
Barbados 147	5.24	.06
Wailuku No. 2	5.09	.06
E. K. 2	5.12	.06
Malagache	1.26	.01
Rose Bamboo	1.42	.02
Bulilao	.84	.01
P. O. J. 2878	24.90	.29
H. N. 35/911 ?	2.78	.03
L. C. 25/191	.99	.01

Luzon

This island produces about 25 per cent of the total Philippine sugar crop. The climate of Luzon is not so well suited to cane as that of Negros. There is an excess of moisture during the rainy season and excessive drought during the dry season.

About three-quarters of the cane acreage of Luzon is planted to Luzon White and Pampanga Red. These two varieties are believed by many to be merely color variations of one and the same cane. They are good all around canes, thriving under a wide variety of conditions, good germinators and sparse tasselers, fairly drought resistant and have good juices. They ratoon poorly and are more or less susceptible to mosaic and to root rot, but resistant to Fiji disease and leaf scald.

In spite of the fact that these canes have certain desirable qualities, those engaged in the testing of new varieties are confident that they will soon be displaced by some of the newer varieties.

Negros Purple is second in importance on Luzon and occupies about one-fifth of the total acreage.

Of the newer seedlings which are giving promise the following may be mentioned:

Young cane suffering from drought in Luzon. To be successful under Luzon conditions a variety must be able to withstand extreme drought during the dry season, and excessive moisture during the rainy season. (Photo by J. P. Martin.)

A cane which up to now has been designated as New Guinea 24-A, but which Dr. Manuel Roxas suspects of being 147 Barbados, is being multiplied and subjected to tests as rapidly as possible. It is drought resistant and very hard. It bends rather than breaks in high winds, and suffers less from typhoon damage and from rat damage than most canes.

Mauritius 1900 is another cane which is attracting attention. It is described as having very good juices, is markedly drought resistant, and a sparse tasseler. It is a short thick type. One of its weaknesses is its susceptibility to mosaic. It is also susceptible to Fiji disease and leaf scald but these two diseases can be easily controlled, according to the plantation men.

P.O.J. 2878 does not look particularly outstanding on Luzon. If one may judge from the plantings seen here it cannot compete to best advantage under conditions of extreme drought or poor soil. According to Dr. Roxas it is not entirely resistant to mosaic and leaf scald and is rather susceptible to Fiji disease. It tasseled up to 60 per cent in 1928-1929. This is considered a great disadvantage because the planters depend for planting material on top seed cut from their harvesting fields. The fact that the native varieties rarely tassel and thus can be relied upon for good top seed at harvesting time is one of the principal reasons for their popularity. The Philippine hacenderos apparently have not learned, as those of Formosa have, to make planting entirely independent of harvesting by the use of seed nurseries to serve as a source of planting material. Seed nurseries have enabled Formosa to successfully utilize P.O.J. 2725—a variety which tassels practically 100 per cent.

We were told that certain fields of P.O.J. 2878 on Luzon had suffered rather severely from typhoon injury and contained much rotten cane when harvested.

On the whole P.O.J. 2878 is not gaining favor on Luzon nearly so rapidly as on Negros. It is not impossible, however, that it may not yet prove to be superior to the present varieties.

H 109 is being grown to a limited extent. It has the reputation of germinating rather poorly in comparison with the native varieties under the dry planting conditions commonly met with. The growers also object to its free tasseling. However, it ratoons better than most varieties under Luzon conditions and it has good juices even at an early age.

P.O.J. 213 is doing well on rather poor soils at Del Carmen.

P.O.J. 2714 and P.O.J. 2727 are being tried, but neither appears outstanding. It is probably too dry for the former, while the latter is very susceptible to Fiji disease.

P.O.J. 2725 which is doing so well under very similar conditions in Formosa has just been imported and is still in quarantine.

Chinois—a Uba cane imported from Saigon, and which Dr. Roxas believes to be identical with our so-called Hawaiian Uba, has given good yields in situations so poor that other canes refuse to grow. The factories discourage the farmers from planting it, however, because of the difficulties in milling.

Yellow Caledonia was planted on rather a large scale on Luzon several years ago but it proved to be susceptible to Fiji disease. The prolonged dry season, too, is probably not to its liking.

Mindoro, Panay and Cebu

These three islands have altogether five centrals, which grind less than 5 per cent of the total Philippine sugar crop.

Mindoro has the largest acreage of H 109 in the Philippines. This variety, according to Mr. Lee's estimate, comprises about half of the total acreage there, with P.O.J. 213 about 20 per cent and Uba about 5 per cent. The native varieties, Luzon White and Negros Purple make up the remainder.

The acreage on Panay is about 85 per cent Negros Purple, 10 per cent D. I. 52 and 5 per cent P.O.J. 2878.

The acreage of Cebu is 100 per cent Negros Purple.

Summary

The principal variety on Negros is Negros Purple. Badila is second in importance and has been gaining in favor. More recently P.O.J. 2878 is attracting much attention. According to present indications it will replace the varieties now being grown on Negros within a few years.

Luzon White and Pampanga Red are the principal varieties on Luzon. These are believed to be color variations of one and the same cane. Negros Purple is second in importance.

Mauritius 1900 and a cane known as New Guinea 24-A (147 B?) have been outyielding the older varieties in tests and are gaining favor.

P.O.J. 2878 has not established itself as rapidly on Luzon as on Negros. However, it may still prove superior to the present varieties.

H 109, P.O.J. 213 and Uba are also grown to a limited extent on Luzon.

The plantings on Mindoro, Panay and Cebu comprise only a small percentage of the total.

The Mindoro acreage consists of H 109, P.O.J. 213, Uba, Luzon White and Negros Purple.

The Panay acreage is planted chiefly to Negros Purple, with a small percentage of D. I. 52 and P.O.J. 2878.

The Cebu plantings consist almost entirely of Negros Purple.

It is quite generally felt that the old native varieties which have dominated the Philippine plantings for so many years will be replaced by canes of greater yielding ability in the near future.

Sugar Cane Breeding in the Philippines*

By A. J. Mangelsdorf

Luzon White and Negros Purple have long been the standard varieties in the Philippines. With their high sucrose content and their tolerance of unfavorable conditions they met very satisfactorily the needs of the industry as it was conducted in the old days.

With improved field practices, however, came the desire for varieties better able to respond to the improved methods. This desire has supplied the necessary incentive for a beginning in cane breeding work.

The growing of seedlings was begun by Dr. N. B. Mendiola, at the College of Agriculture at Los Banos, in 1919. Although seedlings were produced only in limited numbers as compared with some of the other sugar cane countries, much valuable work was done in the development of breeding methods.

More recently the Philippine Sugar Association has undertaken a program of seedling production. Their first crosses were made during the 1927 and 1928 crossing season. The production of seedlings is now being prosecuted by the Association on an extensive scale.

Crossing Methods

The usual method of effecting crosses is similar to the one designated in the Java literature as free crossing. The female tassel is allowed to remain on its own stalk. Shortly before tasseling the female stalk may be trained along the ground so that the tassel, when it emerges, will be in a convenient position for pollination. When the female tassel begins blooming two male tassels are cut, usually late in the afternoon, and are tied in a position so as to surround the female tassel as completely as possible.

Formerly it was considered necessary to suspend a bamboo vase in such a position that the cut ends of the male tassels would be immersed in water. Recently, however, it has been found that if cut late in the afternoon the male tassels will shed their pollen the next morning without being placed in water.

A second method which has been used to a limited extent is an adaptation of the Indian procedure of surrounding several joints of the tasseling stalk with earth, thus inducing it to send out roots, after which the stalk is cut below the "layered" portion and removed to an isolated spot for crossing. Instead of using a clay pot to hold the earth around the stalk as in India, a joint of bamboo of large diameter is used for this purpose. The bamboo joint has several advantages over the Indian clay pot, being lighter in weight, not easily broken, and drying out less quickly.

A third method which has been used with fair success is that of collecting the pollen from the male tassels each morning by shaking them over a sheet of Manila paper. The pollen so collected is then carried to the female tassels and dusted upon

* I wish to express my thanks to Dr. Manuel L. Roxas, Dr. N. B. Mendiola, and others, who supplied the facts reported in this paper.

the newly emerged stigmas. Good germinations are reported from tassels pollinated in this way.

The sulphurous acid method of Hawaii is being followed with good success at Victorias.

Crossing under bags has been used to a very limited extent only. As in most other countries this method has been largely replaced by others because of the poor germinations which usually result from bagged tassels.

At Los Banos, plantings of breeding canes have been made at elevations of 300 and 1500 feet on the slopes of Mt. Maquiling. These differences in elevation have been found to influence the time of tasseling to such an extent that it has been possible to make crosses which would have been out of the question had the two parent varieties been grown at the same elevation.

Varieties Used as Parents

In the early stages of the seedling work at Los Banos, field collected tassels were used and no parentage records were kept. In recent years, however, complete pedigrees have been kept of the seedlings produced.

Dr. N. B. Mendiola, of the College of Agriculture at Los Banos. Dr. Mendiola and his students have contributed much to the progress of cane breeding in the Philippines.

H 109 has been rather extensively used as a female parent by the Philippine Sugar Association because of its good juices and good ratooning ability.

Hind's Special, a cane which is grown by the Negritos in the mountains of Zambales is being extensively used as a male parent. There is some evidence that it is a natural hybrid between one of the noble canes and the native Philippine form of *Saccharum spontaneum* known locally as "Talahib." Hind's Special is a hardy, vigorous cane and is said to have very fair juices.

Toledo, another cane which is believed to be a chance *spontaneum* hybrid is also being used to some extent in crosses. It tends to have poor juices but it is quite vigorous.

Badila, contrary to its usual behavior in Hawaii, tassels very freely in the Philippines and is widely used as a male parent.

Attempts have been made to use the Uba canes in breeding work, but as in Hawaii they have proved rather highly sterile and have usually given only a few seedlings. In 1929, however, several hundred seedlings per tassel were reported from Chinois, a Uba from Saigon, crossed with New Guinea 24A.

C.A.C. 87 is a thin, vigorous cane which is being extensively used as a male parent in crosses with the noble canes. Like Toledo and Hind's Special, it is believed to be an accidental hybrid between one of the thick canes and Talahib. Its appearance bears out this theory—it resembles Kassoer and U. S. 666 (a Kassoer seedling) quite closely.

Surprisingly enough the two principal Philippine varieties, Luzon White and Negros Purple have been little used in breeding work. These two canes have some desirable qualities, which if transmitted to their seedlings, should make them valuable breeding material. We refer especially to their good juices and their tolerance of drought and other unfavorable conditions. The sparse tasseling of Luzon White is also a very desirable quality which adds interest to this cane as breeding material.

More recently the Java canes, P.O.J. 2878 and P.O.J. 2883 are being used in crosses in the Philippines. Dr. Dwight Pierce, who was formerly associated with the Victorias Milling Company of Negros, told us that P.O.J. 2883 crossed with Badila has given them more promising seedlings than any other combination tried thus far.

Nursery Methods and Selection Procedure

The climate of the Philippines is, of course, much more tropical than that of Hawaii, and the germinating equipment, such as greenhouses and heated tables which we have found essential in Hawaii are unnecessary there. The fuzz is sown in low boxes, which are kept covered with panes of glass until the seedlings have become established.

Up to the present time it has been the practice to prick out the seedlings into other flats when they have reached the age of a month or so. At present, however, pricking into nursery beds is being tried, as in India, and with good success.

When they are three to five months old the seedlings are set out in the field. Here the rows are 40 inches apart and the seedlings are spaced 30 inches apart in the row.

The first selection is made when the seedlings are about a year old. Disease resistance is considered the most important point to be watched. Seedlings found to be infected with mosaic or other diseases are eliminated at once. The percentage infected with mosaic is usually high. Seedlings from crosses involving wild (*Saccharum spontaneum*) blood have been found to show a much smaller percentage of mosaic infection than other crosses.

Tasseling is considered a serious disadvantage and canes which tassel heavily are eliminated. This policy is based on the fact that the growers depend on the harvesting fields for their planting material. Tasseling results in seed which is unsatisfactory both in quality and quantity.

Splitting of the rind is considered a serious defect. It is believed that these splits permit the entrance of red rot infection.

Erect canes are preferred—those which lodge are discriminated against. Lodging usually results in serious deterioration in the Philippines, due to breaking of stalks, followed by rat damage and subsequent rotting. Canes of medium length or less, which compensate for their lack of length by free stooling are preferred for this reason.

Good juices and satisfactory milling qualities are also listed among the more important qualities to be looked for in seedling selection.

Out of a list of 20,000 seedlings grown by the Philippine Sugar Association in 1928 at Canlubang and Del Carmen, 400 (about 2 per cent) were retained after the first selection. Fifteen to twenty cuttings were taken from each and planted out to a second trial. No check rows were used in this second planting but we were told that in the future such tests will contain alternate rows of a standard variety for comparison.

Number of Seedlings Produced

While the success or failure of cane breeding work is by no means determined by the number of seedlings grown, it is of interest to examine the census of seedlings produced to date.

Grown by the College of Agriculture at Los Banos:

Year	No. of Seedlings Grown
1920	4,377
1921	223
1922	755
1923	743
1924	2,756
1925	1,325
1926	50,000*
1927	100
1928	14,412
1929	5,000

Grown by the Philippine Sugar Association at the Del Carmen and Canlubang Station.†

1928	20,000
1929	15,000

Grown at the La Carlota Sugar Cane Experiment Station:

Up to 1929	12,608

Approximate total for all stations—127,300††

* Of this number, 20,000 were sent to the Philippine Sugar Association Station at Del Carmen and 10,000 to Pasudeco.

† Approximate.

†† In addition to the above the Victorias Milling Company has produced a number of seedlings, the exact figures for which are not at hand.

The following list shows the number of seedlings grown by the Philippine Sugar Association in 1929, with their parentages. It is interesting to note that a wide range of parents is being used including several which are highly regarded as breeding canes in other countries. It is evident from this list that the importation and use of breeding material is receiving considerable thought and attention.

Parentage	No. of Seedlings Set Out
H 109 x Co. 205 (1)	7,511
H 109 x P. S. A. 7 (2)	1,052
H 109 x P. S. A. 143	366
H 109 x P. S. A. 3	56
H 109 x Cane X-4	344
J 247 (3) x Co. 205	1,340
J 247 x Co. 205	501
J 247 x Hind's Special	293
D 1135 x Co. 205	675
N. G. 24A x Hind's Special	613
N. G. 24A x Cane X4	40
Cebu Purple x Co. 205	192
Lahaina x Co. 205	193
Lahaina x Co. 205	18
Lahaina x Hind's Special	226
Lahaina x C. A. C. 87 (4)	153
Rose Bamboo x Co. 205	226
Badila x Hind's Special	201
Badila x P. S. A. 19	18
Louisiana Striped x Co. 205	89
P. S. A. 7 x H 109	84
Mauritius 1900 x Hind's Special	77
Q 409 (5) x Hind's Special	77
Q 409 x C. A. C. 87	36
C. A. 12735 x Cane X 4	40
Chinois x N. G. 24 A	79
Chinois x Badila	12
Toledo x J 247	227
Toledo x H 109	224
Toledo x C. A. 12735	151
Toledo x Badila	52
Total	15,166

Breeding Work at La Carlota and Victorias

The following notes, kindly supplied by Dr. Roxas, give a review of the breeding work at the La Carlota Sugar Cane Experiment Station, at La Carlota, Occidental Negros. This is a Government Station under the direction of the Bureau of Plant Industry.

(1) Co. = Coimbatore.
(2) P. S. A. = Philippine Sugar Association.
(3) This refers presumably to the Java cane 247 B.
(4) C. A. C. = College of Agriculture cane.
(5) Q = Queensland.

The total number of sugar cane seedlings produced in the station since the beginning of the work is 12,608.

The total number of seedlings eliminated so far is 10,361.

The total number of seedlings now being propagated is 2,247.

The five most promising seedlings are the LC 22/4, LC 25/191, LC 25/138, LC 25/210 and LC 25/476.

The method of crossing is by natural hybridization, that is, hybridization without emasculation.

The method of selection is by elimination of the poor strains.

The qualities looked for in parents are high tonnage of cane, high sucrose content, resistance to prevalent diseases and pests, resistance to drought and excessive water, etc.

A letter from Carlos Locsin to Dr. Roxas gives some interesting comments on the breeding work at the Victorias Milling Company, Occidental Negros. We quote from it as follows:

This is only our third year of seedling work. My two promising seedlings of the first year are only on their way to preliminary trial and the second year seedlings will not come to the test for juice quality until February. So that really there is hardly anything to talk about. I have even avoided mentioning any results of this work in my report on experimental work on sugar cane.

As to breeding methods, we have used free crossing in the field, layering by bending the stalks in the ground and getting the two arrows to be crossed together in the field, potting soil around the cane stalks and crossing under shed and finally the sulphurous acid method. I prefer this last method and used it extensively this year. Next year I plan to use this method exclusively preparing our stock solution in the laboratory. This year some of the solution we used was locally prepared and some from 8 per cent stock solution brought from the States. Undoubtedly the solution loses strength on the way as we find only around 6 per cent of the sulphurous acid in the solution upon arriving at Victorias. A breeding rack that will hold the canes and keep the solution bottles under cover is a great convenience. A model of such a rack was illustrated in one of the recent issues of *Facts About Sugar*.

We find the common red Victorias soil perfectly suitable for use in the seed germinating boxes. It drains well and does not harden. We mix it with some press cake, sterilize and sift it before use. From the original seed boxes we transplant the seedlings in a second series of boxes when about 4 to 6 inches high and from there to the field when sufficient root system has developed. We use a field of red Victorias soil for growing the seedlings. Very few seedlings are lost from transplanting. This year I made up my mind to try transplanting from the original seed boxes to the field to save one transplanting operation. I think under conditions here this can be done with very little loss of seedlings.

List of Philippine Seedling Series

It may be well to record here the various series of Philippine seedlings:

The P. B. (Plant Breeding) series are temporary numbers given to selected seedlings by the College of Agriculture.

The C. A. (College of Agriculture) series includes the canes which were selected and given permanent numbers during the first few years of seedling work. In the future those receiving permanent numbers will be designated C. A. C. (College of Agriculture Canes).

The P.S.A. seedlings are those selected by the Philippine Sugar Association.

The L. C. seedlings are those selected by the La Carlota Sugar Cane Experiment Station.

The C. S. E. seedlings are presumably those selected by Calamba Sugar Estate. (This is based on surmise only—we have no information on this series.)

Results Obtained

In view of the fact that the breeding work was begun only some ten years ago, too much cannot be expected as yet in the way of results.

The testing of seedlings is a slow process,—one in which time is a very necessary element. It is only by following the performance of a seedling through a succession of crops that its value can be determined.

In this respect the Philippines have an advantage over Hawaii in that twelve-month crops are the rule as compared with our sixteen- to twenty-four-month cycles. On the other hand, the selection work there cannot proceed as rapidly as in Java, where only plant crops are grown. In the Philippines, as in Hawaii, ratooning ability is an important consideration, and the necessity of testing the seedlings for their ratooning ability prolongs the selection period.

Of the seedlings produced in the earlier stages of the work, a small number have been selected as showing promise: C.A.C. 111, P.S.A. 3, 6, 7 and 14, C.A. 12735 and 15723 are especially mentioned.

To these should be added the La Carlota seedlings L. C. 22/4, 25/191, 25/138, 25/210 and 25/476 and the Victorias seedling "Esperanza de Victorias."

None of the above seedlings are being grown on an extensive scale as yet, and it remains to be seen whether any of them will be able to displace the present varieties.

It seems certain, however, that if the breeding work is continued on its present scale the development of seedlings better suited to Philippine conditions than the canes now being grown is only a matter of time and persistence.

Summary

Cane breeding in the Philippines was begun by Dr. N. B. Mendiola, of the College of Agriculture, at Los Banos, in 1919.

Relatively few seedlings were produced during the first five or six years. During this period attention was centered chiefly on the development of crossing and nursery technique.

The Philippine Sugar Association now has under way a program of breeding work and is producing seedlings on an extensive scale.

The La Carlota Sugar Cane Experiment Station and the Victorias Milling Company on Negros are also growing and testing seedlings.

Of the local canes, Luzon White, Negros Purple, Hind's Special, C. A. C. 87 and Toledo appear to have characteristics which make them of special interest as breeding material. These together with the large number of varieties imported from other countries afford an excellent assortment of material for breeding work.

Between 100,000 and 200,000 seedlings have been grown since the beginning of the work.

A few of the earlier seedlings are showing promise, and are being tested against the present varieties.

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An Open Letter to All Sugar Technologists*

At the Third Congress of the International Society of Sugar Cane Technologists, held at Sourabaya, Java, in June, 1929, the following resolution was unanimously adopted:

> Whereas, the current technical literature on sugar cane and beet is published in a large number of periodicals and often is written in a language which is only understood by a minority of the technologists or is not available in the local libraries;
>
> Whereas, further reënforcement of interest of organizations and of the personal members of our Association is desired for further development of the activities of the Association;
>
> Be it resolved, that a new periodical be started containing (or an existing periodical be requested to print) adequate abstracts in the English language, submitted by the authors themselves of all technical papers of more general importance;
>
> And be is further resolved, that a committee be appointed by the chairman to devise ways and means for carrying this resolution into effect.

Publication Plan Adopted

The committee appointed in accordance with this resolution and consisting of H. P. Agee (Hawaii), chairman; K. Douwes Dekker (Java), R. Fernandez Garcia (Porto Rico), A. H. Rosenfeld (Louisiana), and W. B. Saladin (Cuba), has given this project very careful consideration, and has discussed a number of plans. The first of the two methods mentioned in the resolution, viz., publication of such a journal under the financial responsibility of the Society itself, has been deemed to be impracticable in the present status of our Society, because the latter has no funds available to apply to such an undertaking, and a campaign for the needed funds, even though possible in itself, would greatly delay the launching of the periodical. The second plan, however, appears feasible immediately, and the chairman of the committee, with the approval and consent of the other members, has authorized the general chairman of the Society to enter into negotiations with E. W. Mayo, Editor of *Facts About Sugar*. A preliminary conference accordingly has been held between Mr. Mayo and the general chairman of the Society, and the former has agreed to publish all abstracts which the Society may furnish through any or all available channels. A section with appropriate heading will be set aside, and pursuant to the wishes of the committee, abstracts concerning the agricultural phase of the cane sugar industry will be separated from those relating to the manufacturing side. Owing to the character of the Society, sugar beet growing for the present will not be considered, but it is desired to include beet sugar manufacture, because in the manufacturing field the problems of the two industries are in many instances quite similar.

Supply of Abstracts

Turning now to the question of the abstracts themselves, it has been the custom with journals of a similar character to employ paid abstractors, each one of them taking care regularly of a certain number of journals of a certain specialized

* Taken from *Facts About Sugar*, Vol. XXV, June, 1930, pp. 579-580.

branch of knowledge. The Society is at present financially unable to pursue such a course. But it is believed, and this belief is expressed in the text of the resolution, that every author who is interested in having his work published and made known to the world is quite as much interested not only in securing as large as possible a circle of readers for his own publications, locally as well as universally, but also in having ready and convenient access to all the literature in his field appearing anywhere in the world, in any language. After an author has taken considerable time to collect his data and to put them down in words, it requires only an additional fraction of the time consumed to prepare an abstract giving the salient features of the article. It is often said that trained abstractors are better able to do this than many of the authors themselves. While this may be generally true, the writer has noticed not a few instances where an abstractor has missed a point or misconstrued the statements of an author. Another important point is that abstracts, in contradistinction to critical reviews, should be informative only, and the preparation of the abstracts by the authors themselves safeguards this feature. A certain amount of editing of the abstracts is necessary, to be sure, in order to guarantee a uniform policy; this part of the work will be handled by the Technical Editor of *Facts About Sugar,* in cooperation with the officers of the Society.

The cooperation of all the sugar journals all over the world, of government departments, experiment stations, local technologists' associations, etc., will be necessary and is earnestly solicited. In some cases it may be possible to make special arrangements with established abstract journals to reprint abstracts of articles appearing in other than sugar journals, which are of interest to sugar technologists, such as, for instance, on sugar chemistry, plant physiology, phytopathology, the various branches of engineering, and such like.

The Editor of *Facts About Sugar* has also offered to furnish reprints of the abstract pages at cost, in the more handy form of 15 x 23 cm., with two columns instead of three. An exact price per year cannot be fixed until it is known how much space will be required.

Cooperation Necessary to Plan

The success of the journal will depend entirely on the interest shown and on the amount of cooperation given by each member of the Society and by each author, whether or not he is a member of the Society.

The publication of the abstracts will begin as soon as a sufficient number is received by the Editor of *Facts About Sugar,* 153 Waverly Place, New York City. Orders for subscriptions to the reprints should also be addressed to him. It is intended to include all articles which have appeared since January 1, 1930, so as to have a complete record for the present calendar year. Authors please note!

A supply of copies of this letter will be sent to each vice-chairman of the Society, and they will be requested:

(1) To distribute these copies among the members of the Society. Additional copies will be sent on request.

(2) To point out to all sugar technologists in their territory the necessity of sending in abstracts of all articles they publish, not later than the time they appear in print. In some cases where publication is liable to be delayed, it will be preferable to forward the abstract when the article is transmitted to the publisher; the abstract will in such cases be held at the office of *Facts About Sugar* and the reference inserted after the article has actually been published. General directions concerning the nature and style of the abstracts are given below: they are patterned after those adopted by *Chemical Abstracts.*

(3) To examine periodically all the technical sugar literature published in their territory and to ascertain whether all of it has been abstracted and abstracts have been forwarded. If any articles have been omitted, the vice-chairman is requested to send the titles of them to the Editor of *Facts About Sugar,* preferably accompanied by the abstract.

The vice-chairmen are further requested to notify the Editor of *Facts About Sugar,* on the return card sent to them, whether they are willing to cooperate in the way indicated above. If for any reason they are unable to undertake these duties they are expected to appoint a committee of one or more members in their territory who express a willingness to act in that capacity.*

Any articles noted in the literature by the Technical Editor of *Facts About Sugar,* for which articles no abstracts have been received in a reasonable time, will be reported by title only. It will therefore be to the interest of each author to send in abstracts promptly. The responsibility for the success of the new venture rests upon each individual sugar technologist.

F. W. Zerban,
General Chairman.

GENERAL DIRECTIONS FOR ABSTRACTING

Nature of Abstract—The abstract should contain all important new information in sufficient detail to give a clear idea of what has been accomplished. The general reader should not find it necessary to refer to the original, and the specialist should be able to judge from the abstract whether or not he will have to do so. Abstracts of articles which originally appear in any of the less known languages, especially those of the Slav and Asiatic groups, should generally be given in greater detail. The abstracts of technical research work should not be in the form of summaries merely stating the subject treated and the results obtained, but should be analytical in nature, along the following general plan. They should include, in the order given, a statement of:

(1) The purpose of the investigation.

(2) The methods by which the worker has approached his subject, and by which he has obtained a solution of his problem.

(3) The results actually obtained, and the conclusions drawn by the author of the article.

* Note—The following committee has been appointed to deal with abstracts for the Hawaii branch of the International Society of Sugar Cane Technologists: J. P. Martin, A. J. Mangelsdorf, O. H. Swezey, F. E. Hance, H. L. Lyon, W. R. McAllep. (H. P. A.)

Such analytical abstracts are not necessary in the case of articles which merely represent discussions, restatements, or reviews of the literature, new books or monographs, criticisms of other articles, etc. In these cases descriptive abstracts will usually suffice, each individual instance to be judged separately by the author and editor.

Language—All the abstracts are to be published in English, but if the author who prepares the abstract is not sufficiently conversant with that language, they may be sent in in Dutch, French, German, or Spanish, and such abstracts will be translated through the editorial office.

Abbreviations—No abbreviations should be used by the authors. The editor may introduce suitable abbreviations, a key to which is to be printed in the journal.

Manuscript—Whenever possible abstracts should be typewritten, double spaced, on one side of the paper only. If the author is unable to furnish typewritten copy, he should write as legibly as possible.

Heading of Abstract—The headings should invariably be given in the following order:

(1) Title of article.

(2) Full names of author or authors.

(3) Name of journal.

(4) Serial number of the volume of the journal.

(5) Page number on which the article begins and page number on which it ends, with a dash between the two, thus: 512-625.

(6) Year in which the article has been published, in parentheses, thus: (1930).

An example follows:

Polarization apparatus with photo-electric indication. W. E. Dickes. Z. Zuckerind. Czech. Rep. 51, 379-80 (1927).

Tables, Graphs, and Drawings.—These should be used only when the information cannot be given in words in less space. In some cases graphs and drawings may actually save space; they should be sent in such form as to be reproducible without redrawing.

Reference—References to previous literature should always be given, to assist the research worker. As soon as this journal has become established, reference should be made to abstracts previously appearing in it.

Rat Control in Hawaii

By C. C. Barnum

Introduction

Since the publication by this Station of the Entomological Series Bulletin 17, dealing with "The Field Rat in Hawaii and Its Control," by C. E. Pemberton, in June, 1925, there has been nothing published in Hawaii relative to rat control excepting progress reports appearing from month to month in the Director's *Monthly Letter*. These progress reports first appeared in October, 1928, and continued until June, 1929, covering the period during which the investigations herein reported were conducted.

This paper presents a general review of previous work done here and elsewhere on rat control and, in detail, the results of an eight-month investigation on rat control conducted on the island of Kauai. The investigations on Kauai were begun at the request of J. T. Moir, Jr., manager of The Koloa Sugar Company, Koloa, Kauai, who offered every facility during the period of study for the continuation of the problem and who put into practice during this time the practical recommendations which have proved effective in controlling the rat population at The Koloa Sugar Company and elsewhere.

Damage Caused by Rats

Damage by rats to produce and property in the United States amounts to about $200,000,000 annually. On certain plantations in Hawaii it has been estimated that 20 per cent of the stalks showed rat injury. In one instance the losses were estimated on one plantation to be 25 per cent to 40 per cent of the crop while similar losses have doubtless been suffered by several plantations in other locations. The damage done by rats on the coffee plantations of Kona has been estimated at $75,000 to $100,000 annually. The rats remove entire branches bearing fruit and eat only the ripest coffee berries. The injury is considerable in that the fruit-bearing wood is lost as well as the crop. The losses in grain and food materials stored in barns and warehouses throughout the Territory are often considerable.

Kinds of Rats

There are in Hawaii three distinct species of field rats, which are classified as follows:

The gray rat, *Rattus norvegicus* (Erxlelen).
The black rat, *Rattus rattus* (Linn.).
The white-bellied black rat, *Rattus rattus alexandrinus* (Geoffroy).

The gray rat is predominant and is the largest of all at maturity. It eats the most food. A large gray rat will eat one pound of sugar cane daily. Three

healthy adult wild gray rats were caught and separately caged. Each rat was fed daily for six successive days one pound of sugar cane which was cut into short lengths and split open to facilitate mastication. Each rat was provided with a daily supply of drinking water. On the seventh day the cane had all been eaten in each cage. Under field conditions probably more cane is consumed daily by each mature rat.

The tail of the gray rat is shorter than his body and the ears are smaller than those of the black rat. This rat is variously named the brown rat, wharf rat, sewer rat, migratory rat, or Norway rat. The average body weight of an adult gray rat is 325 grams or 0.7 pound.

The black rat, or house rat, eats almost as much sugar cane per day as the gray rat, but is somewhat smaller in size. The white-bellied tree or roof rat is a subspecies of the black rat. Both the latter rats have tails longer than the bodies and have very large prominent ears. Pemberton (1) states that the three species of rats above named, were introduced into Hawaii by sailing ships in the nineteenth century.

The practically extinct native Hawaiian rat, *Rattus hawaiiensis,* as described and named by Stone (2), may still exist on outlying coral islands and reefs, but is extremely rare throughout the inhabited parts of the islands. Living specimens of this species have been trapped in 1915 and 1917.

Rats and Bubonic Plague

All rats may carry fleas. Rats are subject to bubonic plague. Fleas carry bubonic plague germs from rat to rat. When a rat dies of plague the fleas leave the dead body and preferably move to the body of a living warm-blooded animal. Should such fleas choose a human being as host that individual would probably be bitten by the fleas in a short time. Such bites often result in the development of plague symptoms within a few hours. A person affected with plague seldom recovers. The rats examined by Pemberton (1) at Honokaa carried the true plague flea, *Xenopsylla cheopsis* (Rothchild). On one rat thirty-two plague fleas were found. The "Black Death" of London in 1665 was a very severe epidemic of bubonic plague in which over half of the population of London was wiped out. The rats acted as mechanical carriers of the disease and the fleas as transmitters of the infection. The causal organism of plague, *Bacillus pestis,* forms such large groups of bacilli as to plug up the entrance to the stomach of the flea. As pointed out by McCallum (3) in his text, such fleas being constantly hungry, will bite again and again, each time transferring plague bacilli to the victim.

Plague exists at present along the Hilo and Hamakua coasts of Hawaii, and so far as known at present nowhere else in the Territory of Hawaii. Plague first appeared on the island of Hawaii in Hilo in 1900, when five human cases occurred. Eleven people died of plague on the Hamakua coast in 1922. Eight persons died of plague during the year ending June 30, 1928, as reported in the Annual Report of the President of the Board of Health of the Territory of Hawaii for that period. The Territorial Board of Health maintains, under the supervision of C. Charlock, Chief Sanitary Inspector, a laboratory at Hilo to which

all rats trapped along the Hilo and Hamakua coasts are shipped daily. The rats are dissected and carefully examined each day at the laboratory in Hilo. Every rat is tagged at the time of removal from the traps; the tag indicates the exact location where each rat was trapped. The bodies of these rats are examined for any symptoms of plague. Should any lesions be found that would indicate a case of plague, direct inoculations are immediately made into guinea pigs kept for this purpose. Laboratory tests are also made to determine the presence of the plague bacillus in the lesions. During the year ending June 30, 1928, twelve rodent plague cases were determined.

Should these guinea pig inoculations prove positive the region where this particular rat was caught is heavily poisoned or extensively trapped, or both, in order to exterminate the rat population in that locality as soon as possible. The constant systematic investigations of the Board of Health have undoubtedly prevented severe epidemics of plague during recent years. Pemberton (1) holds that plague-infected rats are more numerous in dry years than in similar periods of heavy rainfall.

Breeding Habits

Rats multiply rapidly. A single pair of rats may produce a progeny of 800 rats in a single year. This is due to the early maturity of the young. Sexual maturity is reached at 3 to 4 months. The period of gestation is 21 days. The average litter of young is 10.

The ratio of males to females is generally considered about equal. Of rats trapped in Hawaii, the majority have been females.

Natural Enemies of Rats

Dogs and cats are common enemies of rats and doubtless kill many. Dogs, especially at harvest time, kill large numbers of rats in the harvest fields. The effect on the rat population is, however, negligible.

Pemberton (1) points out the value of the mongoose, *Herpestes griseus,* in rat control. This animal, a native of India, was introduced into Jamaica in 1872. The mongoose was introduced into Hawaii, Maui and Oahu in 1883 direct from Jamaica, West Indies, for the purpose of controlling the rats. No introductions were then made or have since been made into Kauai. The result has been that the observed rat damage on Kauai in 1927 and 1928 was uniformly higher than on either Oahu, Maui or Hawaii.

Pemberton (1) in determining the diet of the mongoose, found that it consisted primarily of rats, mice and cockroaches. In some countries rats are partially controlled by snakes. No snakes exist in Hawaii and will not be admitted to these islands under the present quarantine regulations.

Rat Abundance

Due to the rapid multiplication of rats under the favorable conditions of climate and environment in Hawaii, the number of living rats in cane fields at harvest

time is often unbelievable. In one field at Grove Farm Company on Kauai, over 2000 live rats were dug out of the ground and killed by men and dogs after the crop had been removed early in 1929. At the Lihue Plantation Co., Ltd., on Kauai, the harvesting gangs are followed by men and dogs to kill the rats. Since 1922 the Grove Farm Co. has trapped rats, for the first two years using five men steadily and thereafter using only one man throughout the year. The following table presents the facts in this instance:

Year	Number of Rats Caught	Average Number of Rats Caught per Month	Average Number Rats per Trap per Month
1922	23,634	1,929	....
1923	35,206	2,939	....
1924	8,926	744	7.44
1925	8,724	725	7.25
1926	8,470	705	7.05
1927	9 945	828	8.28
1928	6,674	556	5.56

Average number of rats caught per month per trap for seven years, 7.11.

Since July, 1929, the number of rats caught per month has fallen off considerably due to the very thorough distribution of poison during the spring months of 1929. E. H. W. Broadbent, manager of Grove Farm Company, has made a continuous fight against rats during the past 10 years and his cooperation in the experimental use of the various poisons and new methods of distribution utilized in the recent campaign against rats has been of great benefit to all concerned.

On Kipu Plantation on Kauai during the year 1928 a total of 10,935 rats were trapped on field borders and killed in the harvest fields. Through the use of the recently developed thallium rat poison the rat population of Kipu has decreased and the percentage of rat-eaten canes coming to the mill has been decidedly reduced.

Nesting Habits

Rock piles, waste land, woodland, and any kind of shelter provide nesting places for rats. In the coffee district the lava rocks in and about the coffee plantings provide excellent hiding places, especially the stone walls surrounding the fields. The nests of the field rats in cane fields are largely under the ridges between the lines of cane as well as in stone walls and rock piles. The rats provide nesting places which will not be submerged by irrigation or excess rain. A portion of the runway is usually above the water level. Burrows may extend several feet along the line of cane. The nests are usually 6-8 inches in diameter and lined with dry grass or cane trash.

Food Habits

In rat depredations on coffee lands the rats cut off the young branches loaded with coffee, drop these to the ground and eat only part of the fruit. They thus injure more than they eat. The greatest damage is caused by the removal of the

fruiting branches. In avocado culture rats eat portions of attached fruits, thus destroying large quantities.

In cane fields the small part of the stalk usually eaten is insignificant, yet the entire stalk may die and as a result of fungus invasion, decay, and yield little or no sugar. Rats may eat practically all of one stalk or all of several in one stool. The feeding is mostly nocturnal. Once the rat has located a satisfactory mature stalk he returns successive nights to the same stool of cane, until all stalks are eaten, in part at least. Other stools near by are then selected and destroyed. This results in the lodging of the cane and finally at harvest, a great number of dead stalks which have been cut off by the rats are left in the fields. This dead cane must be destroyed by burning, or be removed from the field before starting the succeeding ratoon crop of cane. Where rat damage has been severe it has often been estimated that 10 to 12 tons of cane per acre were left on the land after harvest. In addition to the sugar loss there is also the additional expense of destroying this dead cane material to be added to the actual loss caused by rat injury. In addition a great deal of the partially rat-chewed canes has been sent to the mill. Rat-chewed cane has been shown to be often so badly injured as to yield only 50 per cent of the sugar that the same weight of healthy cane would have yielded.

The extensive investigations conducted at the Paauhau Sugar Plantation Company on the 1924 crop and reported by Elliott (4) are by far the most complete of available records of damages resulting from rat infestation of sugar cane fields. In this work 26 experiments were conducted, each of which comprised 10 acres. Elliott found that 32 per cent of the cane at harvest was partially eaten by rats. Estimating the losses of sugar at 4.50 cents per lb., it was determined that the average losses caused by the rats amounted to $33.35 per acre, or $1.04 for each 1 per cent of rat-injured cane. It was also very clearly shown that approximately two tons more of rat-injured cane was required to produce a ton of sugar than was required of healthy sound cane.

Elliott (5) conducted further tests on the 1927 crop at Paauhau Sugar Plantation Company consisting of a total of 169 experiments on rat-damaged cane. The crops of 14 fields were intensively studied. Including the stalks which were both rat-eaten and borer-damaged with those rat-eaten only, stalk counts indicated that the total averaged 13.67 per cent. The sugar lost in the rat-injured canes amounted to 17.52 per cent. These investigations were confined largely to D 1135 cane.

Recent investigations conducted by Van Zwaluwenburg during February, 1930, on rat and borer damage to cane at Paauhau Sugar Plantation Company indicated that both rat and borer damage increased rapidly after the canes were 16 months old. It was determined by actual count that the percentage of rat-eaten and borer-damaged stalks averaged 22 per cent in D 1135 cane over 17 months old.

This figure corresponds with that obtained by the writer on Kauai where counts of rat-eaten canes were made in the harvest fields. The average of these counts made in rat-infested fields was found to be 22.5 per cent. Several thousand stalks were counted in this work on six plantations.

Counts of rat-injured cane sticks or pieces of cane at the mills, reported by McCleery and Elliott for the 1930 crop, show a decrease in rat damage over counts made on previous crops. Counts were made at 29 mills by members of the staff of the department of sugar technology during the grinding of the 1930 crop.

In the report on these counts, made by McCleery under date of July 30, 1930, the approximate percentages of rat-injured canes for the four islands appear as follow:

Approximate Percentages of Rat-Injured Sticks Observed
Crop 1930

Islands	No. of Mills Inspected	Per Cent Injured Canes
Kauai	8	1.1
Oahu	5	0.53
Maui	5	1.3
Hawaii	16	2.0

Counts made in previous years by this department have not been as comprehensive as this and comparative figures for previous years are not available.

The losses in sugar caused by rat depredations can be calculated as 0.140 per cent of total probable sugar for each 1 per cent of rat-damaged cane coming to the mill. This figure has been derived by Elliott, from cane analyses made at Paauhau Sugar Plantation Company.

Rats cannot live on sugar cane alone. There is not sufficient protein in cane to supply the animal needs. Rats must, therefore, eat insects and seeds of various plants, including those of weeds and grasses. The ready availability of such food assures the rats of a good livelihood and under such conditions rats will multiply rapidly. The knowledge that rats demand a protein diet led to the use of poisoned grain for rat bait. At Honokaa Sugar Company where a systematic scheme was developed to poison rats with prepared baits, strychnine-treated wheat was used extensively.

Rat Control Methods

The Use of Traps:

Trapping is far too expensive, and never has been successful in Hawaii in controlling rats in the cane field. Extensive trapping has been conducted continuously for several years on the plantations along the Hamakua Coast of Hawaii. Here the average number of rats caught per trap per month has never been higher than seven and has often been as low as one rat per trap per month. This condition is not due to a scarcity of rats, necessarily.

The Use of Virus:

The theory that rats can be inoculated or infected with a bacillus which will cause an epidemic of a widespread nature in the rat population of a region badly rat-infested has been advanced. On the other hand rats have been plague victims for generations and yet we have innumerable rats.

Pemberton (1), of this Station, secured direct from the Agricultural Experiment Station at Sugamo, Tokyo, Japan, on December 8, 1922, fresh cultures of the bacilli of Loeffler, Danysz and Mereshkowsky. In Japan, such viruses have

been reported as having been successfully used against rats and mice. These cultures were added to baits which were tested on caged wild rats at Honokaa but all attempts to create disease epidemics among these rats failed. Both rats and mice were fed freshly prepared cultures as well as the commercial preparations, without success. If the negative results so obtained were due to age of the cultures in question, this alone would make the use of such preparations impossible here in Hawaii. A representative of a mainland drug firm was sent out to Honokaa, bringing with him fresh cultures of rat virus and he, in cooperation with Mr. Pemberton, conducted tests on living rats without success. The work done by Mr. Pemberton is considered conclusive and since that time no further investigations have been made with any forms of rat virus in Hawaii. In spite of the publicity given to rat virus and its much-advertised control of rats, there is little foundation for the statements made regarding its successful use. The United States Biological Survey in 1925, reports the annual expenditure in the United States of $500,000 for bacterial rat viruses.

A danger from rat virus is pointed out by Dean (6) as follows:

> Severe cases of food poisoning have been traced to products arising from the growth of the rat (virus) organisms which have gotten into food products and grown there. It is probably true that these rat parasites will not attack man, but it appears that when they grow in various media outside the bodies of rats, substances are produced which are poisonous to man. Infected rats, before they die, are likely to spread the infesting organism rather generally about the neighborhood, in fact the effectiveness of this method of extermination depends on spread of the infection. As Dr. J. C. Geiger says, a cannery is a poor place to attempt the control of rats by such means.

In the most recent bulletin on rat control by Silver (7) the author points out that on account of dangers incurred in human food poisoning attributed to rat viruses, two State Boards of Health have prohibited the sale of rat viruses within the states. He reports the majority of rat virus tests, conducted by bacteriologists of the United States Department of Agriculture, to have been practically ineffective and unsatisfactory.

The Study of Rat Poisons:

A great deal of work has been done on the problem of poison rat baits. The United States Biological Survey has conducted extensive feeding tests and field trials with various poison baits for rat control during the past twenty years. Their work has pointed toward the use of strychnine, barium carbonate and more recently to red squills for the control of rats. The most recent work on squills for rat poison is that by Munch, Silver and Horn (8). Red squills consists of the dried, powdered bulbous root of squill, *Urginea maritima* (L) Baker, also called *U. scilla* Steinheil. It is a perennial plant growing wild on the coast of southern Italy, Sicily, Sardinia and elsewhere along the Mediterranean Sea. The bulbs are pear shaped, usually from 3 to 6 inches in diameter, weigh from 300 to 2000 grams and are composed of closely overlapping fleshy scales. The bulbs are dried and ground to a fine powder. When mixed with attractive bait this material is said to be very toxic to rats but does not kill domestic animals, including poultry. Red squills is toxic to rats while white squills powder is not poisonous.

Lantz (9) of the United States Biological Survey indicates a very suitable strychnine whole wheat formula for control of prairie dogs. This formula has been adopted as a particularly good one for preparations of strychnine-wheat rat poisons and has been more recently modified for use in preparing the thallium sulfate-treated wheat. This formula, when prepared according to our modifications, provided a paste carrying the toxic substance which formed a closely adhering veneer on the seed coats of the wheat grains. This coating withstood exceedingly vigorous agitation and retained the strychnine content without appreciable loss.

The formula of Lantz with slight modifications in the formula and methods follows:

Modified Strychnine-Wheat Formula

Procedure	Ingredients	Amount Originally Indicated by Biological Survey	Equivalent Weight In Grams or Volumes in CC's.
Dissolve by boiling 15 minutes	Laundry starch in water	1 tablespoonful ¾ pint	9.0 gms. 354.0 cc.
Add	Strychnine alkaloid	1 ounce	28.35 gms.
Add	Baking soda	1 ounce	28.35 gms.
Stir and add (Keeping hot)	Thick syrup (Corn syrup)	¼ pint	118 cc. or 175.7 gms.
Add	Glycerine	1 tablespoonful	24 gms.
Add and stir	Saccharine	1/10 ounce	2.83 gms.
Thin to proper consistency with	Hot water	(Sufficient to make a creamy paste)	
Pour and mix thoroughly with clean	Whole wheat	13 qts. = 22.75 lbs.	10328 gms.
Rinse container to remove paste with and add to wheat.	Water	(Approximately) 50 cc.	

Spread treated wheat to dry without further agitation.

Artificial heat has been most successfully used in drying these preparations. When thoroughly dry the treated grain may be roughly handled without appreciable loss of strychnine alkaloid. This point has been proved by chemical analyses of samples so prepared in which the percentage of strychnine alkaloid before shaking was 0.240 per cent; after vigorous shaking two identical samples showed 0.234 and 0.238 per cent strychnine alkaloid, respectively.

Whole wheat treated according to the above formula is found to be well covered with a shellac-like coating when viewed with the low power of the compound microscope. The crystals of insoluble strychnine alkaloid may be seen embedded firmly in this glossy paste coating. The sweetening of the preparation detracts somewhat from the exceedingly bitter taste of strychnine alkaloid preparations.

The work done on rat control in Hawaii was initiated by W. P. Naquin, manager of Honokaa Sugar Company and Pacific Sugar Mill, in 1918. At that time counts of rat-injured canes in the fields at Honokaa indicated that between 30 and 40 per cent of the stalks of cane had been damaged by rats. As pointed out by F. Muir, entomologist of this Station, in his letter to the director at the time of submitting the paper by Pemberton (1) on "The Field Rat in Hawaii and Its Control," Mr. Naquin was the first plantation manager to start an intensive campaign of rat poisoning. It was early found that commercial rat poisons then avail-

able on the market were not entirely satisfactory, were too expensive for general use and that the preparations quickly moulded when exposed during rainy weather for rat consumption in the open fields. Tests were conducted at Honokaa Sugar Company which indicated that home-made strychnine alkaloid-treated whole wheat and barium cakes were satisfactory economical poison baits for use in the fields. It was observed that the very rapid deterioration of these baits in the field necessitated some form of protection. It was Mr. Naquin who developed the paraffine-dipped paper "torpedo" for wheat distribution and the paraffin-dipped barium cakes, both of which were rainproof for a time sufficiently long to make the use of such treated baits practical.

It was Mr. Naquin's early observation from feeding tests on hundreds of caged wild rats and from field trials with poison baits, both of which were conducted at Honokaa Sugar Company, that many rats were immune to strychnine poison in the usual dosage and that other rats refused to eat the strychnine-coated grains. There was, however, a large proportion of the rat population which ate freely of the strychnine preparations and succumbed to its toxic properties. For the relatively large number of strychnine-immune rats, it was determined that barium carbonate cakes would prove toxic, provided the rats could be induced to eat them. Therefore, the Honokaa Sugar Company adopted the policy of alternating the two poisons in their thorough field distributions. Gangs of men were sent periodically through every fifth to tenth consecutive line in every field of cane, distributing either paraffin-dipped paper torpedoes of strychnine-wheat or paraffin-dipped barium cakes every few feet along the way. In this manner the entire plantation cane area was swept with poison at 30 to 60-day intervals. Both poison preparations were made on the plantation very cheaply. This system, developed at Honokaa Sugar Company, proved highly successful in reducing rat losses to a minimum. Mr. Pemberton, who went to Honokaa at the request of Mr. Naquin, cooperated in this investigation. Mr. Pemberton conducted a series of tests on 428 caged wild rats at Honokaa during 1922 and 1923. A great number of different kinds of baits and poisons were tried. Many, such as arsenic, red squills, phosphorus and cyanide were tried and regarded as unsatisfactory. The best results were obtained with strychnine alkaloid and barium carbonate.

The strychnine was used in association with whole wheat or barley. The barium was prepared as barium cake made of 1 part barium carbonate to 4 parts of wheat middlings, made into a heavy paste with the addition of water, rolled into thin layers, cut into small cakes and dried thoroughly. These cakes were then dipped in hot paraffin to waterproof the material.

Attractiveness of Bait

Much emphasis has been falsely placed on odors and flavors as attractive factors in rat bait preparation. Boulenger (10) points out that of 27 different kinds of foodstuffs, including bread, meat and fish of various kinds, vegetables, oils and fruits, ordinary bread was the most attractive both to caged rats and to rats at large. Cereals, fruits, meats and oils, in the order named were less attractive than bread. The author states:

Food faintly flavored with oils of Rhodium and Anise seed, instead of improving the bait had the contrary effect. . . .

Contrary to the statements in many books on the subject of rat destruction, meat, except tripe, and fish, even when smoked, were **only accepted** when no other food was available.

Stanley P. Young, of the United States Biological Survey, states, in a letter to this Experiment Station January 3, 1929, that: . . . . "the sense of smell is not as well developed in the rat as in many of our other animals. We have been unable to find any value in the use of odors to attract rats to baits. . . . . The chief odorous rat repellant is naphthalene." Highly odorous baits are not necessarily more attractive than those less odorous. Soft, odorous meat baits have proved highly attractive to ants and roaches, and have consequently proved correspondingly less attractive as rat baits. Dry cereal baits do not attract ants and are attractive to rats.

Commercial Uses of Rat Poisons

The Honokaa Sugar Company at Honokaa, Hawaii, has prepared on the plantation both a strychnine-wheat bait and barium cakes during the past seven years. At each distribution the entire plantation was covered by placing baits at frequent intervals in every fifth or tenth line of cane.

The result of this campaign has been a reduction in amount of rat-injured cane coming to the mill. The amount of rat-injured cane which prevailed before the rat campaign at Honokaa was estimated at 25 per cent of the stalks. It was less than 4 per cent at the beginning of the 1929 crop. The home manufacture of strychnine-wheat has provided the plantation with a rat bait having a strychnine content approximately 0.301 per cent, which has been somewhat higher than any of the commercial preparations at present on the market. The United States Biological Survey published in 1925 a statement to the effect that the annual expenditure for chemical rat poisons in the United States amounts to $1,380,000 and that the total annual expenditure for rat control is more than $2,000,000.

The recommended strychnine content of strychnine-coated rat baits has been set at 0.25 per cent by the United States Biological Survey, which has done a great deal of work on the subject of rat baits. Some of the commercial rat baits offered by manufacturers of strychnine-wheat rat bait analyze less than 0.25 per cent strychnine.

On Kauai, during 1928, well over 90 tons of strychnine-wheat were used by the several plantations concerned in rat control. The control obtained by the use of these large quantities of strychnine-wheat was not at all commensurate with the cost of bait and distribution. Rat injury continued and losses amounted to as much as 10 to 12 tons per acre of dead cane which was often left in the fields, in addition to the vast amount of partially eaten cane taken to the mill. Additional labor costs were incurred in either burning or removing this mass of dead cane from the harvest fields.

The milling of such partially eaten and often soured canes resulted in extremely poor juices and lowered the sugar yields considerably. These losses became so marked that J. T. Moir, Jr., manager of the Koloa Sugar Company asked to have

an investigation conducted during the summer of 1928 to determine better methods of control of the rat population on Kauai.

Rat Investigation on Kauai

A preliminary survey was made during September, 1928, and rat feeding tests were begun on wild rats retained captive in screen cages at Koloa Sugar Company. Tests were conducted to determine the toxic value of the packages of strychnine-wheat, called "torpedoes," which were being distributed in the cane fields at that time. These packages containing one heaping teaspoonful of wheat each, were wrapped in single sheets of toilet paper and dipped in melted paraffin to make them waterproof.

It was early determined that rats preferred to eat the packaged wheat that had not been dipped in paraffin, rather than the dipped torpedoes. It was also soon discovered that the undipped packages were more poisonous than the dipped packages. Rats which were fed torpedoes of strychnine-wheat which had not been dipped in paraffin often died after eating a single such torpedo. Similar rats were able to eat several dipped torpedoes before dying and the time interval before death was often two or three times as great as for the rats fed undipped torpedoes.

The cause was found to be partially due to the fact that the paraffin had penetrated the thin tissue paper package and coated the wheat grains as well as the paper. Since the rat ate the grains without removing the wax from the seed coats, the coating of strychnine on the seed coat was sealed over with wax, and, since paraffin wax is indigestible, the strychnine layer beneath the wax coating was held in an indigestible matrix. This condition thus made the poison value of these packages very low, since such a small portion of the wheat was free of paraffin. It was found that only 25 per cent of the wheat in such torpedoes was free of paraffin.

In addition to this indigestible feature of the strychnine coating on the grain contained in such waxed torpedoes, the results of analyses made by the chemistry department of the Experiment Station showed that the strychnine content of much of the strychnine-wheat then being used ran as low as 0.14 per cent. This condition was found to be due to the non-adherence of the applied strychnine alkaloid, which, being insoluble in water, was made to adhere to the grains through the use of a cold starch paste. It was also found that starch which had been boiled for 15 minutes in order to break down the starch grains became extremely adhesive. Strychnine alkaloid could not be easily removed from wheat grains which had been treated with a paste composed of the drug mixed in a boiled starch paste. It was found that such preparations should be dried without agitation by artificial heat. Through the adoption of these changes the strychnine content of the rat bait soon rose to 0.25 per cent. The large amount of analytical work done by Fred Hansson, of the chemistry department of the Experiment Station, involved the strychnine analysis of 67 separate samples.

Observance of Rat Immunity to Strychnine

Subsequent to this change in the mode of preparing strychnine-wheat rat bait, it was found that certain rats were able to consume large quantities of strychnine-

wheat without suffering any discomfort whatever. Fifty-four torpedoes of strychnine-wheat were fed to one black rat retained in a screen cage. All were eaten by the rat during the 59 days in captivity. He finally died after eating a portion of a barium cake. The Honokaa Sugar Company reports having fed one black rat with strychnine-wheat torpedoes only for six months. In the following table are the strychnine-wheat-consumption records of 114 rats many of which finally died subsequent to eating single barium cakes or parts thereof.

Number of Rats	Number of Strychnine-Wheat Torpedoes Eaten by Each Rat	Number of Days in Test Before Death
1	35	42
1	13	14
1	11	14
1	10	11
3	8 each	(Average) 16 each
1	6	(Average) 16
10	5 each	..
12	4 each	..
27	3 each	..
57	2 each	..

At all times caged rats were provided daily with fresh-cut sugar cane, and water in tin containers. To the rats which were found to be immune to strychnine poison we fed barium cakes, but it was soon found that it was necessary to deprive these rats of all other forms of food before they would eat even a small portion of the barium cakes. Whenever such rats ate even small fragments of barium cake, death resulted in a short time.

Cage Tests With Strychnine Wheat

In the cage tests conducted on Kauai with rat poisons of various kinds a total of 483 wild rats and mice were used. Of these a total of 12 rats escaped by chewing at the sides of the box until they were free. A total of 60 rats died of injuries received in trapping or catching them or from natural causes. Poison tests were therefore completed on 411 wild rodents. The rats used in the test were classified as follows:

Species	Number
Rattus norvegicus	327
Rattus rattus	21
Rattus alexandrinus	96
Mus musculus (mice)	7
Undetermined	2
Total	453

During the testing period several kinds of poison baits were used. The number of rats dying from ingestion of the separate poisons are as follows:

Rats poisoned with strychnine	212
Rats poisoned with barium	75
Rats poisoned with thallium	124
Total number of rats poisoned	411

Each rat was given a serial number when caged and was placed in a clean, screened box in which was placed a can of water, several pieces of split sugar cane and one or more torpedoes of the poison preparation under test. Rats numbered 1 to 240 were fed strychnine, which was often followed by barium. The average toxic dose of commercial strychnine-wheat for these rats was 2.5 torpedoes and the average life of the rats was 5.6 days.

In the tests conducted with strychnine-wheat prepared by the United States Biological Survey formula 82 rats were tested. The average number of torpedoes eaten by these rats was 1.4 and the rats lived an average of 5.4 days before the poison proved toxic. Tests were conducted with the commercial strychnine-wheat prepared by the local factory. Torpedoes were made of two kinds of paper. The cheap toilet paper, paraffin-dipped torpedoes were less toxic than torpedoes of the same size and of the same material prepared of a thin white parchment paper called "Fibrespun Bond" which did not allow the melted paraffin to penetrate the paper. The results were as follow:

Comparison of Efficiency of Paraffin-Dipped Torpedoes

Kinds of Paper Used for Torpedo	Average Number of Torpedoes Eaten per Rat	Average Life of Rats During Test
Shasta Toilet Paper.....	3	8 days
Fibrespun Bond Paper.....	1.6	3.4 days

In the search for better adhesive materials for causing adhesion of the strychnine crystals to the seed coats of the grains ordinary glue was used. Carpenter's white fish glue was added in place of starch, using 0.78 per cent by weight. This poison preparation was fed to 18 wild rats, in this instance having the torpedoes prepared from wax paper, not dipped in paraffin. The average number of torpedoes eaten by these rats was 1.3, and the average elapsed time before death of the rats was observed was 4 days. This preparation was by far the most rapid and effective rat bait prepared from strychnine and wheat. The glue was probably more rapidly digested in the gastric juices than the starch paste adhesive material usually used.

The tests conducted with a commercial strychnine-wheat bait produced on the mainland were limited to 7 rats. Six of these rats ate an average of two torpedoes each and lived an average of 7 days under test. One rat ate 12 torpedoes and finally died after eating one thallium sulphate-wheat torpedo.

The tests conducted with the home-made strychnine-wheat prepared by the McBryde Sugar Company, Limited, were made on 21 wild rats. These rats ate an average of 1.5 torpedoes and survived only 3 days. This preparation was made on the plantation by using 5 ozs. of strychnine to each 100 lbs. of crushed barley. This concentration was slightly higher than has been usually used.

Cage Tests With Barium Carbonate Preparations

Barium-coated wheat was tried but the caged rats hesitated several days before eating such bait. A barrel of wheat was treated with 2 per cent barium carbonate, using the adhesive materials as recommended in the United States Biological Sur-

vey formula for strychnine-wheat to serve as a binder for the poison. Field tests were conducted on several plantations but without success. Rats at large did not eat freely of these torpedoes. Feeding tests on caged rats were conducted on 12 wild rats at Koloa. These 12 rats ate 16.4 torpedoes prepared with this material wrapped in "Fibrespun Bond" paper and dipped in paraffin. They lived a total of 97 days. The average toxic dose was 1.3 torpedoes and the average length of time the rats were under test was 8 days before death was observed. Barium carbonate was mixed with dry ground meat scraps but rats refused to eat these preparations. Melted cheese scraps obtained from the Atlas Warehouse and Cold Storage Company, Green Bay, Wisconsin, were tested as a bait with which 20 per cent of barium carbonate was thoroughly mixed. Such bait was made up into small 12-15 gram paper packages or torpedoes which were fed to caged rats. None of this material was eaten by the rats. Pre-baiting with cheese torpedoes free of poison was tried. The rats did not relish the cheese. Such baits were extremely attractive to ants, however.

Canned fish, too soft for ordinary trade purposes, was tried as a bait mixed with barium carbonate. Rats did not relish this preparation. Ants always found the packages in the fields and quickly ate the fish contents.

No case was observed wherein any rat even nibbled of a barium cake until all other food had been previously removed from the cage. This preparation was apparently very distasteful to rats. It was observed that most rats dying from barium poison were found in or near the water container within the cage. No cake was entirely eaten by rats; lethal results were produced by ingestion of only slight fragments. The marked dislike for preparations containing barium carbonate was a general observation of all tests with this preparation.

The strychnine-wheat prepared according to the United States Biological Survey formula proved far more toxic than the bait previously used, yet it did not kill those rats that were immune to strychnine. The McBryde Sugar Company, Ltd., at Eleele, Kauai, cooperated in feeding tests of poison baits. Keith Tester, former agriculturist for that plantation, conducted a large number of tests with various poisons placed in feeding shelters in the fields where the rats were free to come and go. His tests in part are summarized in the following table:

Preparation of Bait	Average Percentage Removed
Strychnine barley and fish (wet)	95
Corn meal, barium and fish (wet)	51
Strychnine barley (dry)	100
Corn meal and barium carbonate (dry)	0

At the stations where fish preparations were fed the ants and cockroaches were big factors in removing the bait. Feeding shelters are well adapted for easily accessible rock piles and along stone walls but for general field distribution of rat baits, the expense of preparing shelters of wood and roofing paper plus the cost of placing them in the field and recovering them later does not seem warranted.

Torpedo distribution of poison in attractive paper packets has proved cheaper and equally effective.

Strychnine barley with and without animal fat added was fed in shelters to wild rats in the field. Very slight preference was shown for the grain treated with

fat. It was observed also that ants prevailed wherever fat-covered wheat was exposed. This condition made such baits less attractive than the fat-free baits.

Mr. Tester's feeding of wild caged rats with strychnine baits and barium baits supported all the tests carried on at Koloa Sugar Company by the writer. The cooperation of the McBryde Sugar Company and of Mr. Tester has been greatly appreciated in this project.

A summarized table follows in which all the tests conducted on Kauai with the various forms of strychnine-wheat and barium carbonate preparations are listed.

Poison Bait Fed to Caged Rats	Number of Rats Tested	Average number of Torpedoes Eaten	Average Number of Days Rat Survived
*Commercial strychnine wheat (Old formula)	85	1.8	4.0
Strychnine wheat (Biological Survey formula)	82	1.4	5.4
McBryde Sugar Co., strychnine barley	21	1.5	3.0
Makee Sugar Co., commercial strychnine wheat	6	2.0	7.0
Strychnine wheat with glue	18	1.3	4.0
Whole wheat plus 2% barium carbonate	12	1.3	8.0
†Barium mixtures after strychnine wheat torpedoes	52	Strychnine 2.1 Barium 1.2	7.0
Barium mixtures only	11	Variable	8.0
Total	287 rats		Average 5.2 days

A search was made for a poison that would replace strychnine and yet not be too expensive. Such a poison was found and developed during this work.

Tests With Thallium Sulfate

Trials were conducted during March, 1929, with the first thallium-treated wheat preparations to be used in Hawaii. The thallium sulfate was used at the rate of 1 lb. to 1000 lbs. of whole wheat and the results obtained in cage tests were very satisfactory. All caged wild rats subsequently fed thallium-treated wheat died from the poisonous effect of this highly toxic salt, even in these small quantities. Increasing the amount of poison to one pound of thallium sulfate for each 750 lbs. of whole wheat gave no better results than were obtained with the weaker concentration. The content of the package or torpedo was maintained at one teaspoonful of the treated wheat, which permitted the preparation of 45 to 50 torpedoes per pound of dry rat bait.

A total of 124 wild rats, held captive in cages, was fed thallium-treated wheat. An average of one torpedo was eaten by each rat and the average life of the rat

* Commercial strychnine wheat prepared according to our old formula at the factory in Honolulu has been used extensively for the last few years.

† These tests were often started with several kinds of strychnine-wheat preparations and one or more forms of barium preparations placed before the caged rat in order to determine rat preferences for such baits. In other cases the barium was given after several strychnine-wheat torpedoes had been eaten without lethal results.

after feeding this preparation was 3 days. All rats to which this poison has been fed in cages have eaten the preparation. No rat refused to eat the preparation in these tests.

The tests conducted on caged wild rats were limited in numbers of individuals used principally because of the difficulty in trapping wild rats. The symptoms of thallium poisoning on rats under observation were extremely easy to detect. Within 24 hours after eating thallium baits the rats appeared to be blind, were extremely inactive and were unable to control the muscles of the hind legs. All rats poisoned by thallium exhibited extreme cases of cataract of the eyes, and the eyes were watery at death. A summarized table of results of our feeding tests in cages follows:

No. of Rats Tested	Ratio of Thallium Sulfate to Wheat	No. of Torpedoes Eaten by the Group	No. of Days Elapsed Before Death Was Observed	Average No. of Days per Rat
6	1-1000	7.5	20	3.3
37	1-1000	41.2	114	3.0
45	1-750	38.0	132	2.8
14	1-1000	16.0	33	2.3
16	1-750	16.0	45	2.8
6	1-1000	6.0	39	6.5
Total 124 rats		124.7 torpedoes	383 days	

Average number torpedoes eaten per rat.....1.0
Average number of days rat lived.....3.0

At McBryde Sugar Company, Limited, Mr. Tester fed 16 caged wild rats each one torpedo of thallium-treated wheat (1-1000 concentration). The single torpedo was toxic in each case and the average life of the rats in the cages was 2.3 days.

The observed difference in time required for toxic results with the higher concentration of the poison indicated that the stronger dose acted the quickest. But inasmuch as all rats which were fed thallium preparations died in due time the value of the lower concentration is fully justified. It is also more economical to prepare and is apparently equally as effectual as the higher concentration of poison.

The thallium-treated wheat was the most readily taken of all the baits tested and caused the death of the individual rats in the shortest observed time. Furthermore, a lesser quantity of the poison bait was required to kill the rats than was needed for any other preparation tested.

The work done by Munch (11) on thallium poisoning is the most recent on this subject. He found that the minimum lethal dose (M. L. D.) for rats was 25 milligrams of thallium per 1000 grams of body weight. When intravenously injected into rabbits the M.L.D. is the same. He states that: " . . . . although thallium sulfate is occasionally given to children (medically) in doses of 8 mg. per kilogram of body weight, it has caused toxic reactions even in doses half that size. Thallium affects the sympathetic nervous system, thereby causing alopecia, pains in the muscles and nerves of the legs, and disturbances of the endocrine glands, particularly the ovaries or testicles. Thallium is cumulative in action; tolerance

does not develop in animals. Thallium is a certain, but not a rapid, poison for rats."

The average weight of an adult gray rat is approximately 325 grams. Therefore the M.L.D. for such rats would be 8.3 milligrams of thallium. Torpedoes prepared from the 1 to 1000 concentration of thallium sulfate-treated wheat which contain not more than 10 to 12 grams of bait would therefore carry a slightly excessive dose of thallium which would insure toxic results when eaten entire by a single rat. Such torpedoes can be prepared by making 45 packets per pound of treated wheat, each containing approximately 10 grams of grain. Larger torpedoes are wasteful, especially if the grains are free of paraffin, which may penetrate the lighter, more porous tissue paper wrappers. Tough non-porous paper is, therefore, best for preparing torpedoes of rat bait.

At the present time all plantations in Hawaii using rat poison in large quantities are using thallium-treated wheat exclusively. Where this poison has been thoroughly distributed in badly rat-infested cane areas the heavy feeding of rats has practically ceased within a week after such distribution. A second distribution of this preparation has usually eliminated the rat population of such areas.

The formula adopted in Hawaii for preparing thallium sulfate-treated wheat is simply a slight modification of the strychnine-wheat formula appearing under the heading "The Study of Rat Poisons." The substitution of thallium sulfate for strychnine alkaloid necessitated a few changes in technique and in equipment.

Iron or copper containers should *never be used* for preparing solutions of thallium sulfate. Glass, porcelain or lead containers only should be used to avoid decomposition of the thallium sulfate. Boiling the solution for any length of time should be strictly avoided as well. At such temperatures the decrepitation (or tendency to "splatter") of the solution makes handling of the preparation dangerous. The starch, however, must be boiled for 15 minutes in order to break down the starch grains. The non-poisonous ingredients may then be added to the boiling starch paste and thoroughly mixed. In conclusion the thallium sulfate may be dissolved in sufficient hot water and mixed thoroughly with the paste preparation. Proportionate parts of the paste preparation are then removed and poured over equivalent amounts of clean whole wheat and thoroughly mixed. The wetted grain is then spread to dry, preferably in the presence of artificial heat, in order to prevent moulding under unfavorable conditions of air-drying.

The following formula is the one at present successfully being used in the preparation of thallium sulfate-treated wheat for rat bait. No operators should attempt to prepare large quantities of this preparation without the *protection of rubber gloves.*

Modified Thallium Sulfate-Wheat Formula

Ingredients	Small Lot, Amounts	Amounts in Grams or CC's	Ton Lot, Amounts	Procedure
Starch	1 tablespoonful	9.0 gms.	2.0 lbs.	
Water	¾ pt.	354.0 cc.	6.8 gals.	Add and boil for 15 minutes.
Baking soda	1 ounce	28.35 gms.	5.5 lbs.	Stir and boil.
Thick syrup	¼ pt.	118 cc. = 175.7 gms.	2.3 gals.	Stir and boil.
Glycerine	1 tablespoonful	24 gms.	4.6 lbs.	Stir.
Saccharine	1/10 ounce	2.83 gms.	8 oz.	Stir.
Thallium sulfate	(in warm water)	10.328 gms.	2 lbs.	First dissolve in hot water. Mix thoroughly after adding to paste.
Whole wheat	13 qts. or 22¾ lbs.	10328 gms.	2000 lbs.	Paste is added to small lots in proportionate amounts and thoroughly mixed.

Treated grain to be spread immediately for drying.

CAUTION: Do not allow this solution or paste to come in contact with the skin until after drying.

History, Source and Uses of Thallium

Thallium, one of the rare elements, was discovered by Crookes in 1863. The name, thallium, means green, due to the formation of a green line in the spectrum. Thallium burns with a green flame. The element occurs in various ores which also contain sulphur. The chemical symbol is Tl; the atomic weight is 204.0.

Most of the commercial thallium sulfate used today comes from Germany. It is a by-product of smelters. The form used is the thallous sulfate, which is more stable than the thallic form. During the past two years a great deal of thallium sulfate has been used in California in control of ground squirrels, but the amount of thallium sulphate used per ton of wheat has been 10 times as much as we are using per ton of wheat prepared for rat bait.

Due to a monopoly of the product, the imported chemical sells at a price which varies from $11.00 to $15.00 per pound. Even though this price seems high, the small amount needed to prepare a ton of wheat, i.e., 2 lbs., is not as costly as the usual amount of strychnine alkaloid used per ton of wheat. There is a saving of at least $20.00 per ton for poison material used.

Thallium as a Drug

This drug was formerly used therapeutically in cases of night sweats of phthisis. It has been extensively used as a depilatory agent. The therapeutic use of thallium has been discontinued on account of the severe cases of human poisoning which have resulted. A great deal of work has been done by German and French investigators on the subject of thallium as a drug and as a poison. The symptoms of thallium poisoning are summarized by Munch (11) in his reference to the work of Kaps (12) as follows: "A short period of excessive gastro-intestinal pain, emesis, nausea, colic and diarrhea which soon changes to obstinate constipation; disorders of the central and vegetative nervous systems; degeneration of the heart, liver and kidneys."

The symptoms of thallium poisoning are somewhat similar to those of lead poisoning, although distinguishable. General symptoms are reduction in vision, cataract, nephritis, alopecia, and endocrine disturbances of various sorts. The discontinuance of thallium as a medicine is certainly warranted.

Toxicity of Thallium Baits to Other Animals

Thallium-treated wheat has been held responsible for the death of poultry, turkeys, and horses during the past year. Whenever such rat baits are to be placed close to camps or poultry runs where the fowls are allowed ordinarily to run at large, the fowls should either be penned up during the time the poison is distributed or at least until the rats have taken the poison. Horses have been allowed access to bags of thallium-wheat and have died from eating the torpedoes.

Where poultry have plenty of available food at all times there is less danger of their taking thallium-wheat baits in torpedoes.

Tests were conducted on two young roosters in which they were fed thallium-treated wheat. Five torpedoes were taken by each chicken in the course of 26 days without any symptoms of poisoning during that time. Only one torpedo was offered to each rooster on any one day of the test. Had they not been able to get plenty of other grain the results might have been different. These torpedoes were purposely opened for the chickens at time of feeding. Three white rats were caged and fed one torpedo each. Within three days all rats were dead. The torpedoes were all from the same lot.

Tests were conducted on Chinese pheasants in relation to the toxicity of thallium sulfate-treated wheat torpedoes through the cooperation of J. M. Kelly, chief fish and game warden of the Territory of Hawaii. Torpedoes were sent to the Territorial Game Farm where tests were conducted by Irwin H. Wilson. Two adult pheasants and two two-month old pheasants were penned and fed thallium-wheat torpedoes unopened. These were not touched by the birds during 48 hours. Other torpedoes were opened and placed in the cages with other grain feed. The pheasants lived 13 days during which time only slight amounts of poisoned grain were eaten. No birds became ill. Six wild rats were caged and fed three similar thallium-wheat torpedoes. Within two days after caging and feeding the rats were dead.

Antidotes for Thallium Poisoning

Very little is known relative to specific antidotes for thallium. The Bayer Company who market a thallium paste preparation known as "Zelio," which they recommend very highly for domestic rat control, states as follows: "Antidote: Call a physician. While waiting, induce vomiting by inserting the finger in the back of the throat. Give an emetic, such as mustard or salt dissolved in warm water. Follow vomiting with Epsom or Glauber salts."

Braun-Knecht-Heimann Company, manufacturing chemists of San Francisco, recommend the following antidote: "Give large dose of Epsom salts in solution of water. Empty stomach as soon as possible by use of stomach tube or emetics."

Buschke, Duchan and Joseph, (13) have investigated the value of sodium thiosulfate as an antidote against thallium poisoning. Mice fed sodium thiosulfate

for 14 days consecutively died within 2 or 3 days after being given subcutaneously a known lethal dose of thallium sulfate.

Where the sodium thiosulfate was given to mice by injection for 14 days prior to injection of known lethal doses of thallium acetate, the mice died within 2 or 3 days. Several mice given simultaneous injections of both thallium acetate and sodium thiosulfate remained alive. One mouse weighing 21 grams, having received 1.4 mgs. of the thallium, died.

Fifteen rats were treated in a similar manner with parallel results. The authors feel that there is no certain basis for using sodium thiosulfate as an antidote.

Buschke (14) states that experiments conducted by himself and Dr. Joseph have been negative up to December, 1928. He points out that the therapeutic action of thallium is not lessened by ministrations of sodium thiosulfate. In Russia a great spread of a fungous disease of the hair has brought about recently the use of thallium salts in medical control. The use of sodium thiosulfate to prevent acute cases of thallium poisoning has been studied by Mrongowius and Duchan (15). Sodium thiosulfate ($Na_2S_2O_3$) has been shown by others to be an antidote for arsenic, mercury and thallium. Experiments conducted on children from 12 to 18 years of age, who were patients at the hospital for skin diseases, indicated that symptoms of thallium poisoning following thallium acetate doses were absent when the patients were given, per orum, 1 to 1.5 gms. of sodium thiosulfate daily. Symptoms of poisoning vanished when sodium thiosulfate antidotes were given for four successive days. Further tests were not conducted. There seems to be evidence to show that in cases of slight poisoning with thallium salts alleviation of pain can be obtained in human beings with 1 to 1.5 gram doses of sodium thiosulfate dissolved in water and taken internally.

Dangers Involved in Handling Thallium

Thallium is very poisonous to man and though it was once used as a drug, this practice has been discontinued on account of the ill effects observed in medical practice.

When in aqueous solution, thallium sulfate is readily absorbed through the skin and is especially dangerous when handled continuously. Such contacts often result in lameness, and falling of the hair. After a time the hair usually is replaced with a new growth.

For those who are handling this poison in an aqueous solution, the use of rubber gloves is recommended. For those who handle the dry thallium-treated wheat, frequent washing of the hands and as little skin contact with the poison-coated grain as possible, is recommended. Frequent washing of the hands and thorough drying are essential to safety in handling this preparation.

The Packaging of Rat Baits

Several kinds of paper are at present used for making rat bait torpedoes. The cheap flat sheets of toilet paper so much used give better service where two sheets are used for each torpedo. There is less penetration of the hot wax through the two sheets of paper. The paraffin should be kept constantly at a temperature

slightly above 120° C. during the dipping process. The torpedoes are held in the hands of the operator by the twisted tops and simply immersed momentarily in the hot wax and after draining for a short time are allowed to cool on large trays. When cool the torpedoes are put into bags for field distribution. Heating of the wax may be secured by the use of a kerosene heater or an electric plate.

A better grade of thin white paper has been successfully used for the preparation of torpedoes. There is little penetration of the hot paraffin through this better grade of paper and though the paper may cost a little more than the thin toilet paper sheets there is less absorption of paraffin and consequently less cost for paraffin used in the dipping process.

The white paper torpedoes have the advantage of greater visibility in the cane field than have the brown tissue paper dipped torpedoes. This is an advantage to both rats and man. The paraffin coating is primarily made as a protection against rain.

In a torpedo which has not been dipped in paraffin the wheat will become mouldy very quickly during or after a rain. Such mouldy grain will not be eaten by rats. Where rainfall is of very rare occurrence, waxed paper sheets are satisfactorily used for making torpedoes. These need not be dipped in hot wax.

Ordinary glassine paper is sometimes used for torpedo-making but a slight shower will cause these torpedoes to become untwisted and later allow rain to reach the wrapped grain. Mould will soon overgrow such packages of grain. The size of the sheets of paper used in making torpedoes varies with the grade of paper used. A sheet of paper 5 x 5 inches makes a very suitable torpedo. The size is usually determined by the most advantageous cutting of the large sheets of stock paper. These sheets usually measure 22 x 36 inches and can be cut without waste into 28 smaller sheets of uniform size.

For convenience and speed in preparing torpedoes a "shaper" has been devised. This device consists of a 1 by 10 inch cylinder of wood attached in a vertical position on a board platform. The upper end of the cylinder should be rounded off to form a hemispherical top. The sheets of paper to be shaped are placed singly directly over the rounded top and shaped down over the cylinder quickly with the other hand of the operator. This produces a cup-shaped receptacle into which the measured dose of rat bait is poured and the paper then twisted to form the torpedo. One operator can usually shape enough single paper "cups" for several workers to fill and finish.

Field Distribution of Rat Bait

Rat bait should be placed near the feeding places of rats. Heavy distribution of baits should be around rock piles in which many rats are living. As long as the applied torpedoes are all eaten the indications are that more rats may be present. Repeated distribution of poison should be made within two weeks after the first application provided indications are present that rats are still feeding on cane in that particular field or region. Irrigators, carrying small bags of torpedoes, often aid in poison distribution by dropping torpedoes where necessary.

Frequent inspection of the interior parts of the cane fields should be made and on finding fresh evidences of rat feeding, poison should be distributed thoroughly, leaving at least one torpedo close by each stool of cane found to be recently partially eaten. Recent feeding can be determined by the light color of the freshly chewed sections of stalk. With age the partially chewed regions on the stalks take on a darker color. This is due to oxidation and the attacks of various organisms, including bacteria, yeasts and fungi.

Rats prefer fairly mature cane which has a fair sugar content. They will not feed on very young plant or ratoon growth. Mature cane fields are the usual haunts of field rats. When the harvesting has been completed the rats which occupied the cane areas are forced to migrate to other suitable-aged canes for food supplies. This is a very logical time to apply poison in the fields to which the rats move, because the young cane in such fields will usually be upright and can be easily inspected and poison applied.

Even in cases of extremely heavy rat infestation, where thorough poison distribution has been made, very few, if any, dead rats will be found. Rats poisoned by thallium retreat to the darkest corners before dying. The best indication of the efficiency of this poison is the cessation of fresh injuries on growing canes.

Poison application on any plantation should be in the hands of one individual who will have charge of the distribution of poison where needed. Rat poison distribution on a sugar plantation should be a year-round process and will under such conditions very rapidly reduce rat damage to a minimum.

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Summary

1. Previous investigations on rat control in Hawaii and elsewhere are reviewed.

2. Rats in Hawaii are limited to three species: *Rattus norvegicus, R. rattus* and *R. rattus alexandrinus.*

3. Partial control of rats is obtained in Hawaii through the activities of the mongoose.

4. Recent investigations have shown that many rats are immune to strychnine poison.

5. Barium carbonate preparations are not attractive to rats, although very toxic even in small doses.

6. A modified formula for preparing strychnine alkaloid-treated wheat is presented. A glue-strychnine-wheat formula which proved effective is also mentioned.

7. Investigations have shown that one pound of thallium sulfate per 1000 lbs. of whole wheat makes a satisfactory rat bait. A formula for preparation is presented.

8. Thallium-treated wheat in these concentrations was toxic to all rats tested.

9. One 10-gram portion of such preparation is a lethal dose for an adult rat.

10. Such portions, wrapped in paper torpedoes and dipped in melted paraffin make excellent waterproof packages for field distribution.

11. Wherever such torpedoes of thallium-treated wheat are adequately distributed in rat-infested regions satisfactory lethal results have been obtained.

12. This rat bait has been adopted for regular plantation practice to control the rat population in Hawaii. Success has attended its use.

13. Antidotes are not well known, but sodium thiosulfate has been recommended.

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Cane Growth Studies at Waipio Substation

EXPERIMENT E

By Arthur Ayres

At the time the 1929 issue of the *Reports of the Association of Hawaiian Sugar Technologists* went to print, while the harvesting of this experiment was complete, the chemical analyses of the samples taken were not. Hence, only a preliminary report, under the above title, by G. R. Stewart and J. A. Verret, was included in that issue.

The harvest data as presented by them (corrected to cover certain errors in calculation pertaining to final extraction of water from the samples that found their way into the above-mentioned paper) plus the analytical results of the last three harvests, recently completed, form the basis of this paper.

No attempt will be made in the present paper to thoroughly interpret the data presented herein. This article will constitute, rather, a brief outline of the experiment, with frequent references to the preliminary report, followed by a somewhat varied presentation of the analytical, in conjunction with the harvest data, and such observations by the writer as may seem appropriate.

Referring to Messrs. Stewart and Verret's article for a description of the experiment:

> This experiment was originally planned and laid out by the agricultural department for the purpose of studying the yield of cane and sugar given by the H 109 variety when planted at different periods of the year. The chemical department was given the opportunity of studying the mineral composition of the cane harvested in these growth studies. . . .
>
> The scheme of the experiment as laid out by the agriculturists was to harvest a series of five plots of cane of graduated age, at equal growth periods, throughout a space of time equal to thirty growth months. At the first period of harvest the planting of the cane had been so adjusted that the cane on the five plots had grown for periods of time equivalent to three growth months, six growth months, nine growth months and twelve growth months. In addition, the weight and composition of the seed cane which would have been employed on one plot were likewise determined. At the second period of harvest the cane was aged three growth months, six growth months, nine growth months, twelve growth months, and fifteen growth months. At each successive time of cropping the youngest plot taken off was three growth months older than at the preceding harvest. It should be clearly understood that the calendar months between each harvesting period were in some cases longer than three months, and in other cases shorter than three calendar months.

The last sentence is confusing. Probably the authors meant "growth months" instead of "calendar months" where the latter term first appears in the sentence. In some instances, in the older plots, there were considerable quantities of dead cane. Where this was the case, samples were selected for analysis. Each plot comprised 1/40 of an acre.

The yield data for millable cane, tops and leaves, trash, and dead cane, on both a fresh and a dry basis are presented in Table I. The yield of sugar is included in this table. These results have all been calculated to an acreage basis. The data are presented graphically in Figs. 1 and 2.

The graphs included in this paper have been worked out on the same principle as those in the report by Messrs. Stewart and Verret. Again referring to their paper:

> In preparing these graphs each crop has been followed through its growth at each successive period of harvest. Thus crop No. 1 is the crop which was seed cane at the period of the first harvest. This crop was three months old at the second harvest, and so on up to eighteen months at the final harvesting date for this crop. Crop No. 2 represents the plot which was three months old at the first date of harvest, and finally reached an age of twenty-one months at the last cropping date. This method of grouping the yield from the different plots appeared to be more logical than simply to group all the plots together which had the same age at the time of cutting.
>
> The fertilization of all the plots was carried out on the following plan: Four weeks after planting, each plot received an application of Waipio complete fertilizer containing 10 per cent nitrogen (N), 7 per cent phosphate (P_2O_5), and 7 per cent potash as K_2O, at the rate of 1000 pounds per acre. Six weeks later, or ten weeks after planting, each plot was given a fertilization with ammonium sulphate, at the rate of 585 pounds per acre. The fertilization was completed by applying ammonium sulphate, twelve weeks later, at the rate of 488 pounds per acre. The total nutrients supplied by this scheme consisted of 323 pounds of nitrogen, 70 pounds of P_2O_5, and 70 pounds K_2O per acre.

The chemical composition of the millable cane, tops and leaves, trash, and dead cane, on a water free basis, is given in Tables IIa, IIb, IIc and IId, respectively.

The number of pounds, per acre, of potash taken up by the stalks and by the entire plant, less roots, for all five crops, is presented graphically in Fig. 3. Values for the latter include the nutrients found in the accompanying trash and dead cane. Corresponding comparisons for phosphate and nitrogen are given in Figs. 4 and 5, respectively. It is of interest to note in these three graphs that the phosphate content of the stalks rises notably during the last three months prior to harvest. This is also true of potash, with one exception, whereas, the nitrogen content drops, during the same period, in every case. In order to show, in a somewhat simpler form, the relationship between the potash, phosphate and nitrogen requirements of the cane plant, less roots, the amounts of these nutrients taken up have been averaged, according to the age of the plant, and presented graphically in Fig. 6. The curve for potash, in this figure, brings forcibly to notice the tremendous demand made upon the soil for this nutrient, running in the oldest crop to well over 800 pounds per acre. This demand is very insistent in the early stages of growth, the plant absorbing nearly 160 pounds per acre between the ages of three and six growth months. The demand for nitrogen after twelve months is nearly constant, whereas, that for potash and phosphate increases constantly and, at certain ages, very sharply. In Fig. 7 is shown the relationship between the amounts of magnesia, lime and silica taken up by the millable cane of the various crops.

In Fig. 8 a comparison is made of the amounts per acre of six different nutrients taken up by the whole plant, less roots. Here again the curves represent the average values for the various crops. The demand made upon the soil for

phosphate, nitrogen and lime appears quite moderate when compared with that for potash.

Since the yield of cane and sugar varies appreciably with the different crops, a basis for comparing the mineral nutrients extracted by them was worked out on a per ton sugar basis. Figs. 9 and 10 show graphically the amounts of phosphate, potash and nitrogen per ton sugar, found in the millable cane of all five crops. Information of this nature may prove of value as an aid in determining the most economical time for harvesting from the standpoint of the mineral nutrients contained in the cane.

Summary

While the amounts of mineral nutrients absorbed by the crop cannot be used as an absolute measure of its fertilizer requirements, the curves showing the quantities of nutrients taken up, indicate the insistent demand of the plant for phosphate, nitrogen and especially potash, during the early stages of growth.

Comparing the oldest completely fertilized crops in the periodic harvesting study at Oahu Sugar Company, Ltd. (reported in *Reports of the Association of Hawaiian Sugar Technologists,* 1929), with the average of crops of equal age in this experiment, we find the potash taken up per acre by the whole plant, less roots, in these two studies to be practically identical. The crops at Oahu Sugar Company, Ltd., took up a much larger amount of nitrogen and an appreciably smaller amount of phosphate than corresponding crops at Waipio. It is felt that much valuable information could be obtained by a thorough and intelligent comparison of these two experiments.

(*Note:* The words "less roots" should appear in the explanations on Figs. 3, 4, 5, 6, 8.)

TABLE I

Periodic Harvesting Results, Experiment E, Waipio Substation

Results Expressed as Tons and as Pounds per Acre—Each Plot 1/40 Acre

Date of Harvest	Age	Crop No.	Cane Stalks, Fresh, Tons	Cane Stalks, Dry, Tons	Cane Stalks, Dry, Pounds	Tops, Fresh, Tons	Tops, Dry, Tons	Tops, Dry, Pounds	Trash, Fresh, Tons	Trash, Dry, Tons	Trash, Dry, Pounds	Dead Cane, Fresh, Tons	Dead Cane, Dry, Tons	Dead Cane, Dry, Pounds	Tons Sugar per Acre
2/15/28	Seed Cane	1	2.67	.57	1,140	.....	.....	....	.....	.....	.....	....	.....	.....	.....
	3 months	2	.....	....	.....	2.62	.397	793	.....	.....	.....	....	.....	.....	.....
	6 months	3	11.09	1.96	3,920	19.28	3.244	6,488	.....	.....	.....	....	.....	.....	.47
	9 months	4	23.51	4.73	9,464	17.86	3.177	6,354	1.75	1.306	2,612	....	.....	.....	1.66
	12 months	5	54.83	12.35	24,700	23.06	4.581	9,162	3.54	2.732	5,464	....	.....	.....	6.03
5/26/28	3 months	1	.....	....	.....	2.96	.658	1,316	.....	.....	.....	....	.....	.....	.....
	6 months	2	10.57	1.678	3,356	23.14	3.574	7,148	1.52	.992	1,984	....	.....	.....	.26
	9 months	3	39.50	8.597	17,194	17.56	3.295	6,590	2.13	1.343	2,686	....	.....	.....	2.58
	12 months	4	45.90	9.028	18,056	14.82	3.131	6,262	5.78	4.081	8,162	....	.....	.....	4.37
	15 months	5	70.66	17.57	35,140	18.54	3.698	7,396	7.50	4.717	9,434	....	.....	.....	7.52
7/23/28	6 months	1	5.48	8.267	1,653	14.72	2.616	5,232	.....	.....	.....	....	.....	.....	.17
	9 months	2	31.43	6.127	12,254	17.52	3.558	7,116	2.48	1.674	3,348	....	.....	.....	2.35
	12 months	3	53.77	12.56	25,120	16.87	3.413	6,826	5.36	4.043	8,086	....	.....	.....	5.32
	15 months	4	59.54	13.59	27,180	16.51	3.424	6,848	6.41	4.950	9,900	....	.....	.....	6.33
	18 months	5	91.55	21.60	43,200	19.15	3.868	7,736	6.69	5.408	10,816	....	.....	.....	9.15
9/21/28	9 months	1	26.36	5.219	10,438	16.08	2.980	5,960	2.72	1.693	3,386	....	.....	.....	1.91
	12 months	2	53.10	11.72	23,440	16.66	3.431	6,862	4.68	3.457	6,914	....	.....	.....	5.65
	15 months	3	65.12	16.68	33,360	16.18	3.191	6,382	5.52	4.227	8,454	.54	.....	.....	7.40
	18 months	4	72.22	16.48	32,960	16.80	3.009	6,018	7.04	5.468	10,936	....	.....	.....	8.40
	21 months	5	107.64	25.76	51,520	19.40	3.981	7,962	8.16	5.847	11,694	....	.....	.....	12.81
2/15/29	12 months	1	53.42	12.98	25,960	17.01	3.106	6,212	9.97	5.277	10,554	....	.....	.....	6.52
	15 months	2	66.29	17.16	34,320	14.03	2.523	5,046	13.21	6.916	13,832	.13	.....	.....	8.30
	18 months	3	90.23	22.84	45,680	12.97	2.582	5,164	15.79	9.023	18,046	1.24	.....	.....	10.72
	21 months	4	99.50	26.71	53,420	14.66	3.046	6,092	19.44	10.27	20,540	2.48	.....	.....	12.64
	24 months	5	125.62	32.74	65,480	13.31	2.712	5,424	19.52	9.627	19,254	4.18	.949	1,898	17.97
5/22/29	15 months	1	59.30	15.44	30,880	14.00	2.723	5,446	6.10	5.184	10,368	.20	.....	.....	5.67
	18 months	2	68.60	17.44	34,880	11.70	2.511	5,022	6.20	4.965	9,930	.62	.....	.....	9.53
	21 months	3	80.0	20.62	41,240	11.70	2.466	4,932	7.70	6.321	12,642	1.30	.642	1,284	12.03
	24 months	4	90.03	24.01	48,020	11.40	2.623	5,246	8.10	6.333	12,666	3.00	1.491	2,982	13.09
	27 months	5	108.9	28.79	57,580	11.40	2.640	5,280	11.50	9.620	19,240	6.50	3.260	6,540	13.96
7/23/29	18 months	1	66.4	17.73	35,460	14.74	2.994	5,988	9.66	7.851	15,702	.86	.....	.....	8.0
	21 months	2	70.0	18.75	37,500	11.56	2.388	4,776	11.50	9.125	18,250	.82	.....	.....	8.97
	24 months	3	82.0	22.86	45,720	13.10	2.812	5,624	11.06	8.578	17,156	2.18	1.244	2,488	11.39
	27 months	4	96.4	25.71	51,420	12.18	3.059	6,118	10.96	9.236	18,472	3.60	2.608	5,416	13.39
	30 months	5	100.0	26.67	53,340	14.00	3.294	6,588	12.26	9.671	19,342	8.74	5.070	10,140	13.51

TABLE IIa

Chemical Composition of Cane, Dry Basis

Date of Harvest	Age	Crop	Per cent Ash	Per cent SiO_2	Per cent CaO	Per cent K_2O	Per cent MgO	Per cent P_2O_5	Per cent N
2/15/28	Seed Cane	1	1.89	0.44	0.065	0.69	0.19	0.086	0.29
	3 months	2	....	....	.....	....	....	.....	....
	6 months	3	2.61	0.60	0.069	0.97	0.19	0.12	0.36
	9 months	4	1.50	0.46	0.079	0.39	0.18	0.075	0.29
	12 months	5	2.03	0.37	0.056	0.88	0.16	0.097	0.25
5/26/28	3 months	1	....	....	.....	....	....	.....	....
	6 months	2	2.16	0.53	0.12	0.76	0.23	0.12	0.38
	9 months	3	1.88	0.41	0.054	0.67	0.16	0.13	0.28
	12 months	4	2.28	0.42	0.058	0.88	0.17	0.13	0.25
	15 months	5	1.93	0.39	0.059	0.79	0.17	0.14	0.22
7/23/28	6 months	1	3.11	0.57	0.15	1.00	0.35	0.16	0.44
	9 months	2	1.43	0.37	0.082	0.39	0.18	0.10	0.23
	12 months	3	1.41	0.43	0.069	0.39	0.16	0.086	0.23
	15 months	4	1.13	0.36	0.056	0.31	0.14	0.068	0.23
	18 months	5	1.54	0.33	0.044	0.59	0.12	0.086	0.21
9/21/28	9 months	1	1.47	0.29	0.090	0.48	0.21	0.093	0.21
	12 months	2	1.54	0.35	0.10	0.40	0.22	0.083	0.17
	15 months	3	1.41	0.41	0.064	0.38	0.15	0.099	0.15
	18 months	4	1.69	0.45	0.071	0.53	0.19	0.13	0.15
	21 months	5	1.88	0.37	0.051	0.72	0.14	0.13	0.14
2/15/29	12 months	1	1.27	0.34	0.069	0.32	0.18	0.090	0.19
	15 months	2	1.49	0.30	0.059	0.51	0.14	0.087	0.15
	18 months	3	1.75	0.42	0.062	0.52	0.17	0.11	0.15
	21 months	4	1.51	0.48	0.057	0.35	0.17	0.12	0.13
	24 months	5	1.78	0.48	0.054	0.56	0.15	0.15	0.12
5/22/29	15 months	1	1.11	0.40	0.075	0.19	0.18	0.09	0.15
	18 months	2	1.59	0.40	0.072	0.51	0.17	0.10	0.12
	21 months	3	1.52	0.53	0.068	0.32	0.18	0.13	0.10
	24 months	4	1.34	0.47	0.060	0.29	0.16	0.13	0.11
	27 months	5	1.77	0.56	0.058	0.49	0.14	0.16	0.12
7/23/29	18 months	1	1.21	0.33	0.062	0.38	0.15	0.11	0.10
	21 months	2	1.52	0.36	0.063	0.47	0.17	0.11	0.10
	24 months	3	1.46	0.48	0.053	0.37	0.16	0.16	0.08
	27 months	4	1.61	0.48	0.062	0.43	0.17	0.17	0.10
	30 months	5	1.81	0.49	0.050	0.56	0.17	0.25	0.09

TABLE IIb

Chemical Composition of Leaves and Tops, Dry Basis

Date of Harvest	Age	Crop	Per cent Ash	Per cent SiO_2	Per cent CaO	Per cent K_2O	Per cent MgO	Per cent P_2O_5	Per cent N
2/15/28	Seed Cane	1	....	....	....	....	....	....	....
	3 months	2	11.13	4.21	0.45	2.96	0.52	0.42	1.54
	6 months	3	9.20	3.20	0.33	2.87	0.40	0.38	1.13
	9 months	4	8.43	2.70	0.34	2.70	0.43	0.38	0.91
	12 months	5	9.59	3.57	0.27	3.03	0.36	0.37	1.01
5/26/28	3 months	1	10.03	3.68	0.34	2.77	0.49	0.42	1.54
	6 months	2	7.12	2.00	0.32	2.26	0.41	0.39	1.11
	9 months	3	8.36	2.77	0.39	2.50	0.45	0.32	0.96
	12 months	4	8.11	2.80	0.47	2.22	0.51	0.30	0.93
	15 months	5	7.95	2.54	0.31	2.83	0.36	0.35	0.93
7/23/28	6 months	1	7.46	2.18	0.33	2.30	0.44	0.37	0.98
	9 months	2	7.72	2.59	0.41	2.19	0.41	0.34	0.92
	12 months	3	7.79	2.37	0.34	2.63	0.35	0.34	0.81
	15 months	4	8.34	3.13	0.37	2.34	0.41	0.36	0.92
	18 months	5	8.42	3.19	0.38	2.41	0.42	0.33	0.85
9/21/28	9 months	1	6.75	1.61	0.32	2.45	0.37	0.41	1.04
	12 months	2	7.47	2.07	0.35	2.72	0.33	0.39	0.93
	15 months	3	8.05	2.69	0.29	2.72	0.31	0.39	0.86
	18 months	4	8.05	2.73	0.27	2.80	0.30	0.43	0.96
	21 months	5	7.82	2.95	0.24	2.63	0.26	0.41	0.85
2/15/29	12 months	1	7.94	2.35	0.36	2.71	0.40	0.40	1.04
	15 months	2	8.14	2.20	0.22	3.13	0.31	0.42	0.87
	18 months	3	8.33	2.66	0.25	2.99	0.30	0.43	0.92
	21 months	4	8.61	3.51	0.25	2.64	0.28	0.42	0.89
	24 months	5	9.15	3.13	0.24	3.12	0.27	0.43	0.81
5/22/29	15 months	1	7.42	2.21	0.28	2.75	0.33	0.37	0.82
	18 months	2	8.03	2.82	0.28	2.73	0.28	0.35	0.73
	21 months	3	8.45	3.13	0.28	2.69	0.31	0.37	0.72
	24 months	4	8.76	3.69	0.27	2.57	0.28	0.37	0.75
	27 months	5	8.59	3.46	0.25	2.71	0.26	0.36	0.79
7/23/29	18 months	1	8.89	3.43	0.30	2.74	0.31	0.45	0.77
	21 months	2	8.44	3.10	0.24	2.78	0.27	0.47	0.71
	24 months	3	9.00	3.59	0.26	2.73	0.28	0.47	0.63
	27 months	4	8.07	3.62	0.27	2.26	0.29	0.44	0.69
	30 months	5	9.14	4.15	0.25	2.53	0.28	0.48	0.75

TABLE IIc

Chemical Composition of Trash, Dry Basis

Date of Harvest	Age	Crop	Per cent Ash	Per cent SiO_2	Per cent CaO	Per cent K_2O	Per cent MgO	Per cent P_2O_5	Per cent N
2/15/28	Seed Cane	1	....	....	....	....	....	....	....
	3 months	2	....	....	....	....	....	....	....
	6 months	3	....	....	....	....	....	....	....
	9 months	4	9.17	5.57	0.57	0.81	0.47	0.078	0.39
	12 months	5	9.72	5.73	0.45	0.86	0.36	0.12	0.51
5/26/28	3 months	1	....	....	....	....	....	....	....
	6 months	2	14.16	9.16	0.85	0.90	0.72	0.080	0.37
	9 months	3	11.99	7.52	0.58	1.26	0.49	0.072	0.32
	12 months	4	10.00	6.01	0.63	0.94	0.62	0.084	0.37
	15 months	5	11.56	7.31	0.58	1.35	0.58	0.089	0.40
7/23/28	6 months	1	....	....	....	....	....	....	....
	9 months	2	10.16	6.12	0.78	0.80	0.62	0.11	0.43
	12 months	3	9.22	4.98	0.57	1.28	0.45	0.11	0.37
	15 months	4	8.89	4.92	0.52	1.31	0.48	0.12	0.40
	18 months	5	9.33	5.65	0.51	1.15	0.46	0.11	0.37
9/21/28	9 months	1	10.65	6.47	0.78	0.79	0.72	0.078	0.33
	12 months	2	8.20	4.12	0.70	1.01	0.58	0.096	0.34
	15 months	3	8.80	5.27	0.58	0.87	0.42	0.079	0.29
	18 months	4	9.27	5.28	0.55	1.09	0.49	0.15	0.37
	21 months	5	9.97	5.64	0.45	1.56	0.46	0.12	0.38
2/15/29	12 months	1	9.73	6.16	0.65	0.42	0.42	0.078	0.32
	15 months	2	9.55	6.56	0.58	0.60	0.36	0.10	0.33
	18 months	3	9.43	6.61	0.49	0.74	0.34	0.12	0.34
	21 months	4	10.39	7.82	0.44	0.51	0.31	0.086	0.30
	24 months	5	10.31	7.76	0.39	0.47	0.29	0.092	0.24
5/22/29	15 months	1	8.37	4.87	0.56	1.04	0.48	0.11	0.32
	18 months	2	9.27	5.33	0.40	1.61	0.37	0.087	0.26
	21 months	3	10.34	6.68	0.49	1.32	0.41	0.096	0.30
	24 months	4	10.42	7.13	0.46	1.10	0.42	0.11	0.26
	27 months	5	10.54	7.58	0.41	0.95	0.33	0.092	0.28
7/23/29	18 months	1	12.11	7.40	0.68	1.55	0.49	0.11	0.30
	21 months	2	11.11	7.43	0.48	1.29	0.32	0.14	0.26
	24 months	3	11.99	7.98	0.43	1.55	0.38	0.16	0.28
	27 months	4	11.98	7.99	0.38	1.64	0.34	0.15	0.27
	30 months	5	12.39	8.45	0.40	1.57	0.37	0.19	0.32

TABLE IId

Chemical Composition of Dead Cane, Dry Basis

Date of Harvest	Age	Crop	Per cent Ash	Per cent SiO_2	Per cent CaO	Per cent K_2O	Per cent MgO	Per cent P_2O_5	Per cent N
2/15/29	24 months	5	3.08	1.10	0.15	0.56	0.33	0.13	0.23
5/22/29	21 months	3	2.48	0.73	0.12	0.66	0.28	0.15	0.20
	24 months	4	2.33	0.87	0.13	0.50	0.29	0.15	0.26
	27 months	5	2.38	0.68	0.95	0.71	0.23	0.17	0.17
7/23/29	24 months	3	2.40	0.66	0.11	0.70	0.28	0.16	0.17
	27 months	4	1.77	0.52	0.073	0.52	0.19	0.17	0.15
	30 months	5	2.23	0.81	0.10	0.56	0.24	0.18	0.14

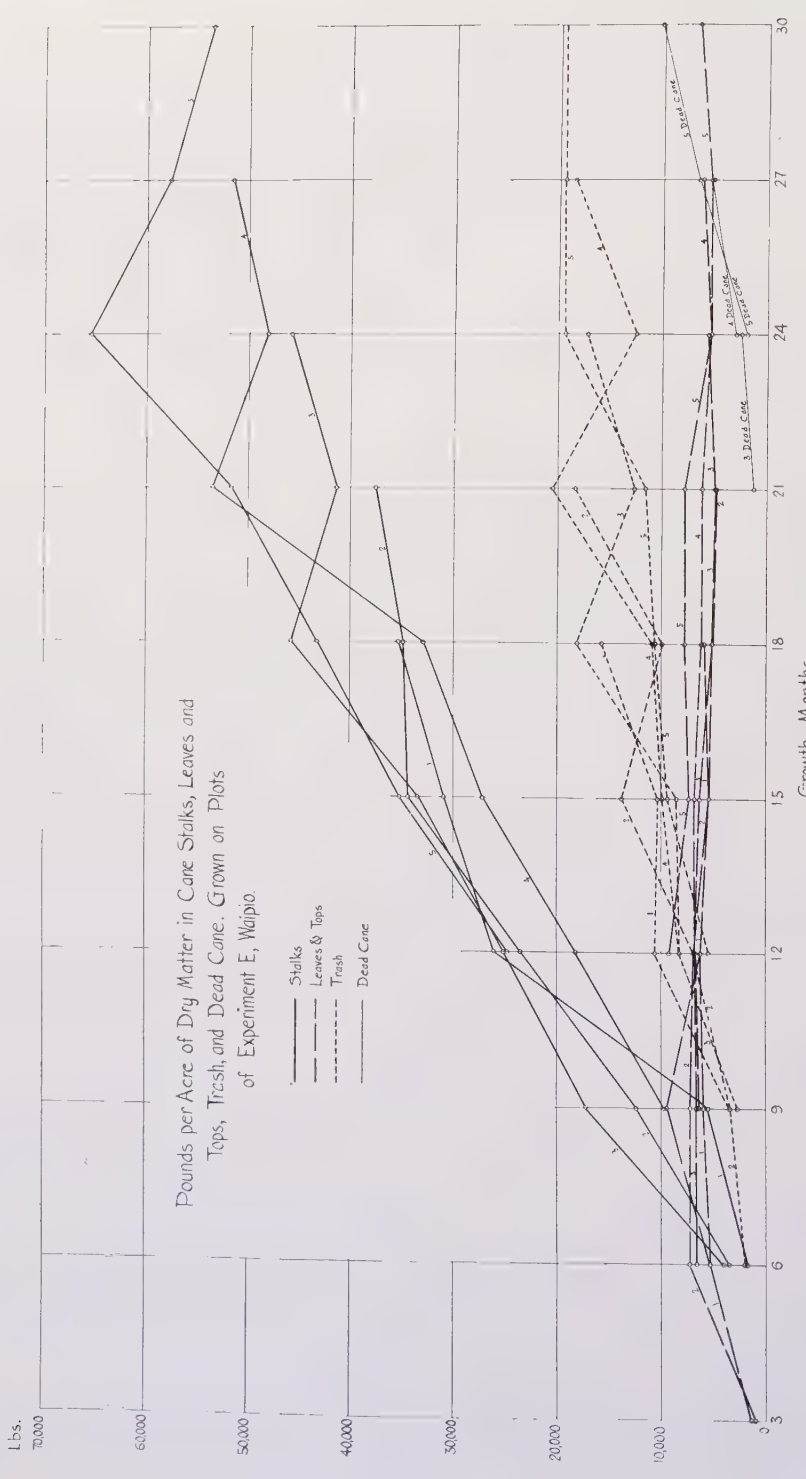

Pounds per Acre of Dry Matter in Cane Stalks, Leaves and Tops, Trash, and Dead Cane, Grown on Plots of Experiment E, Waipio
Stalks
Leaves & Tops
Trash
Dead Cane
Lbs.
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
3
6
9
12
15
18
21
24
27
30
Growth Months
5 Dead Cane
4 Dead Cane
3 Dead Cane

Fig. 1

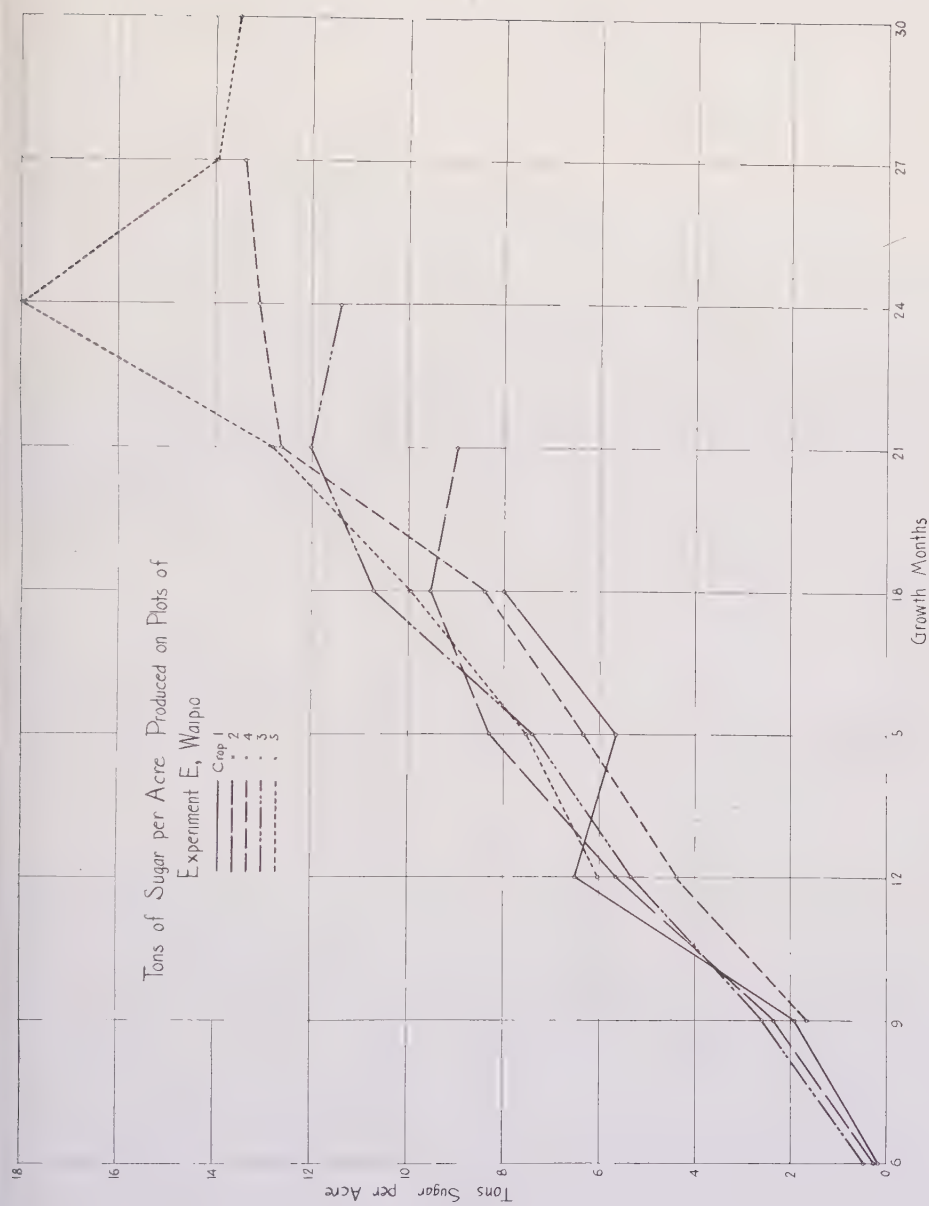

Tons of Sugar per Acre Produced on Plots of Experiment E, Waipio
Crop 1
" 2
" 4
" 3
" 5
Tons Sugar per Acre
0
2
4
6
8
10
12
14
16
18
3
6
9
12
15
18
21
24
27
30
Growth Months

Fig. 2

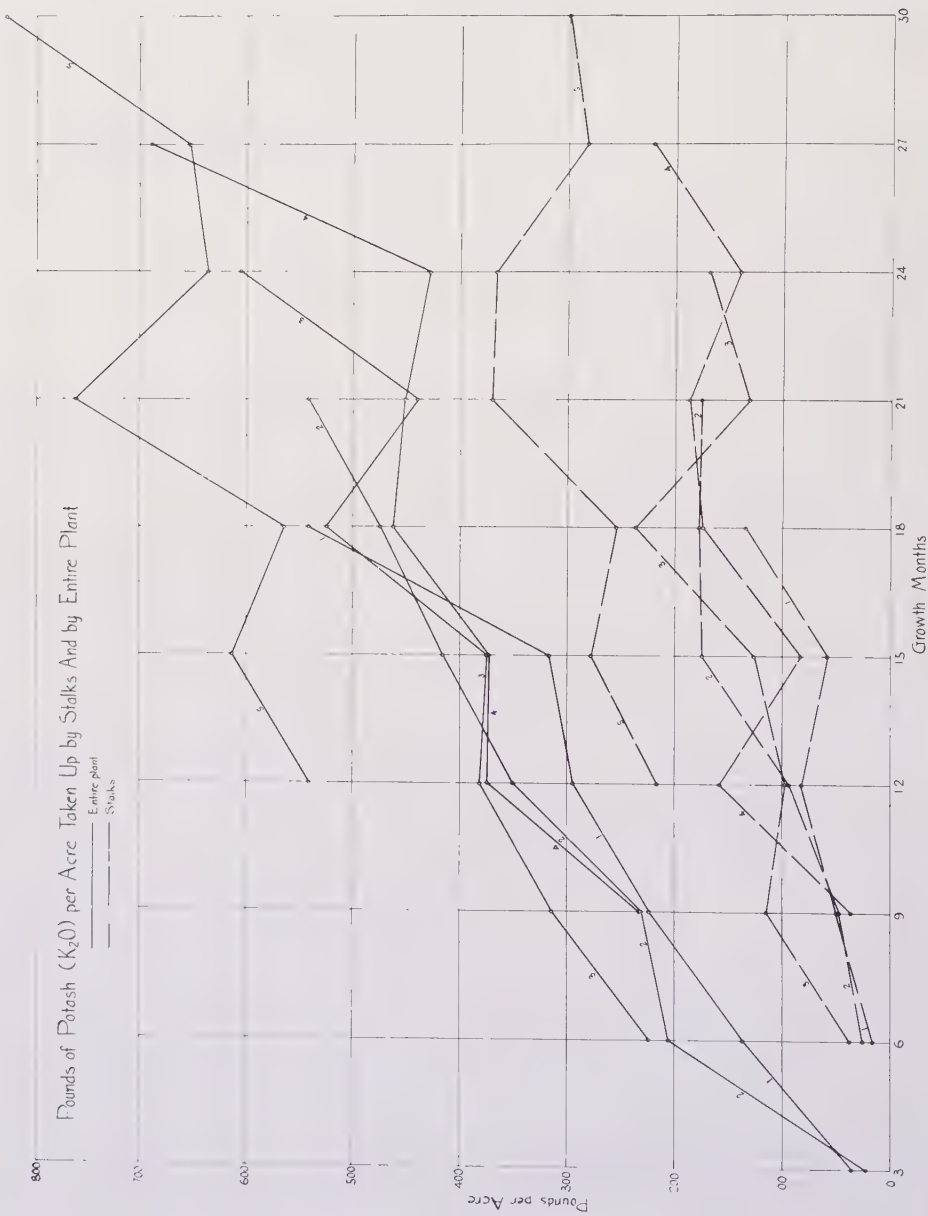

Pounds of Potash (K_2O) per Acre Taken Up by Stalks And by Entire Plant
Entire plant
Stalks
Pounds per Acre
800
700
600
500
400
300
200
100
0
3
6
9
12
15
18
21
24
27
30
Growth Months

Fig. 3

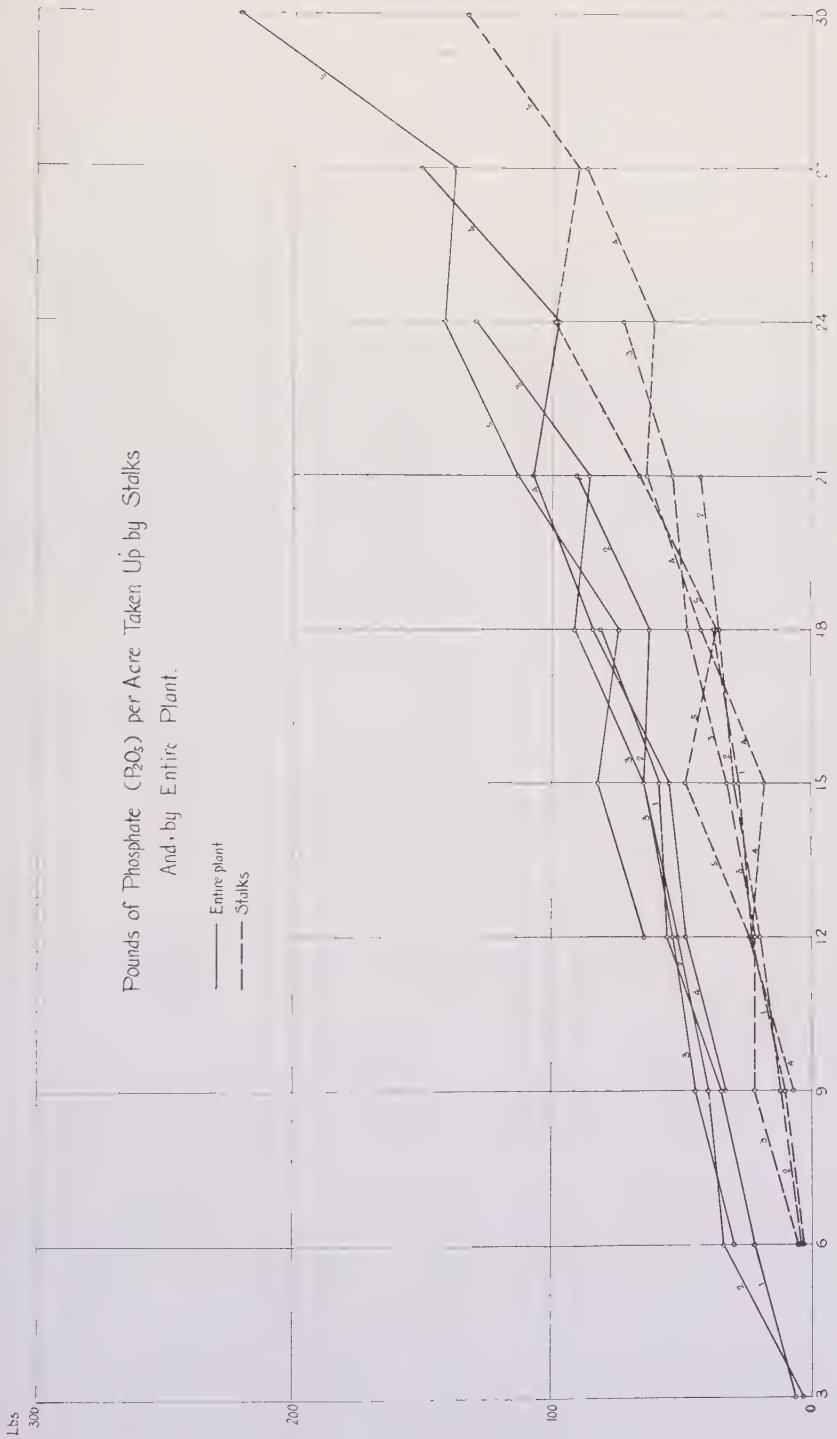

Pounds of Phosphate (P_2O_5) per Acre Taken Up by Stalks
And by Entire Plant.
Entire plant
Stalks
Lbs
300
200
100
0
3
6
9
12
15
18
21
24
30
Growth Months

Fig. 4

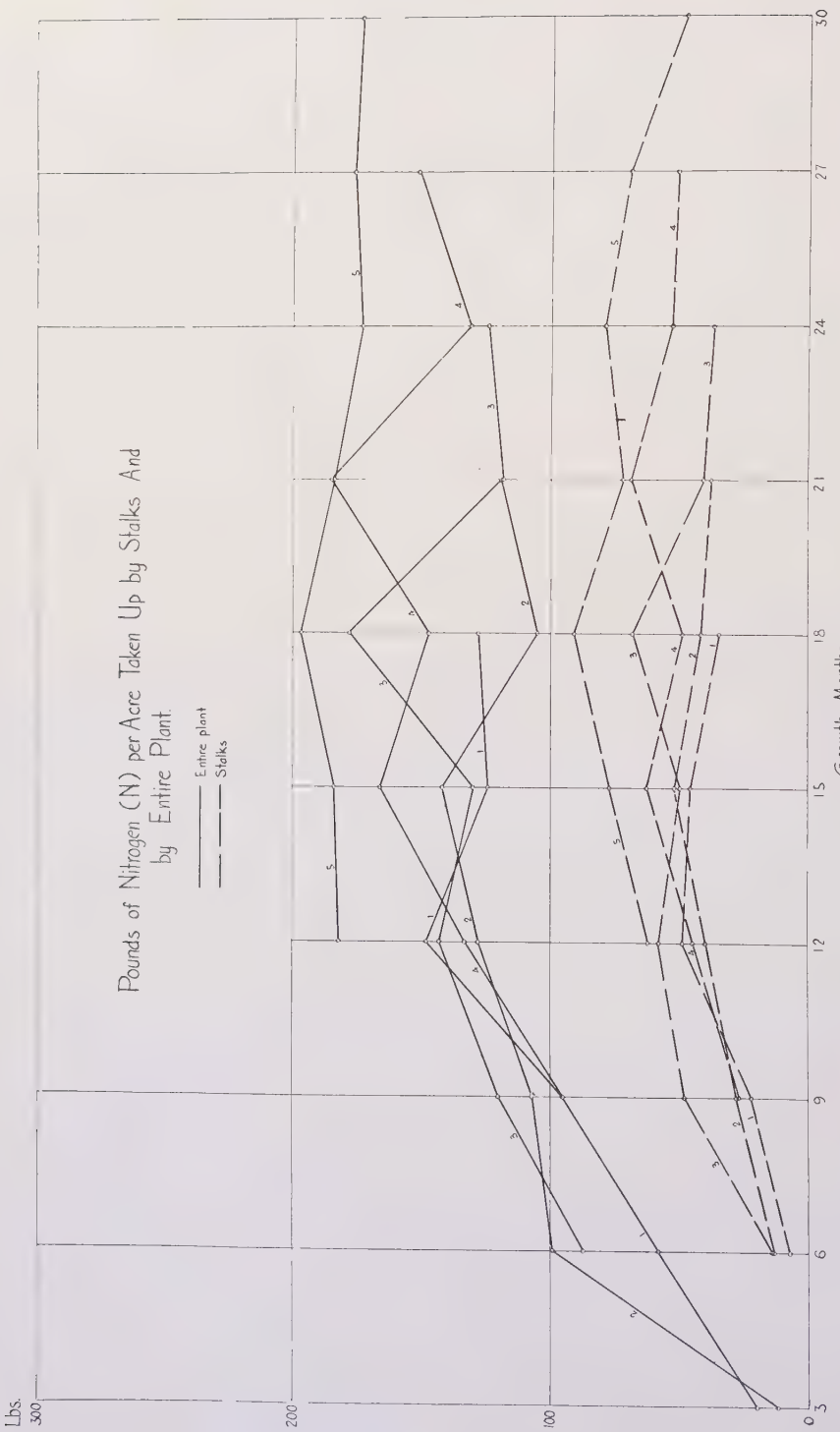

Pounds of Nitrogen (N) per Acre Taken Up by Stalks And by Entire Plant
Entire plant
Stalks
Lbs.
300
200
100
0
3
6
9
12
15
18
21
24
27
30
Growth Months.

Fig. 5

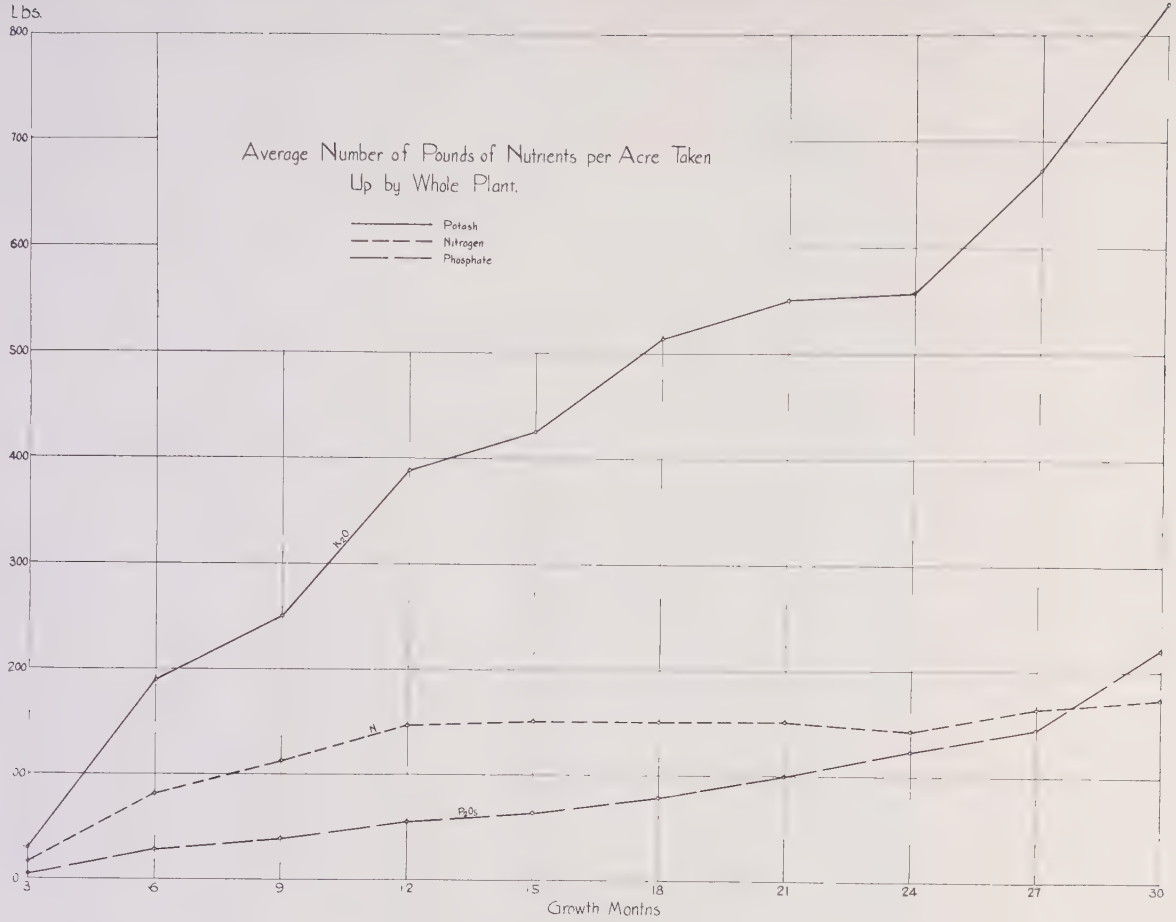

Lbs.
800
700
600
500
400
300
200
100
0
Average Number of Pounds of Nutrients per Acre Taken Up by Whole Plant.
Potash
Nitrogen
Phosphate
K2O
N
P2O5
3
6
9
12
15
18
21
24
27
30
Growth Months

Fig. 6

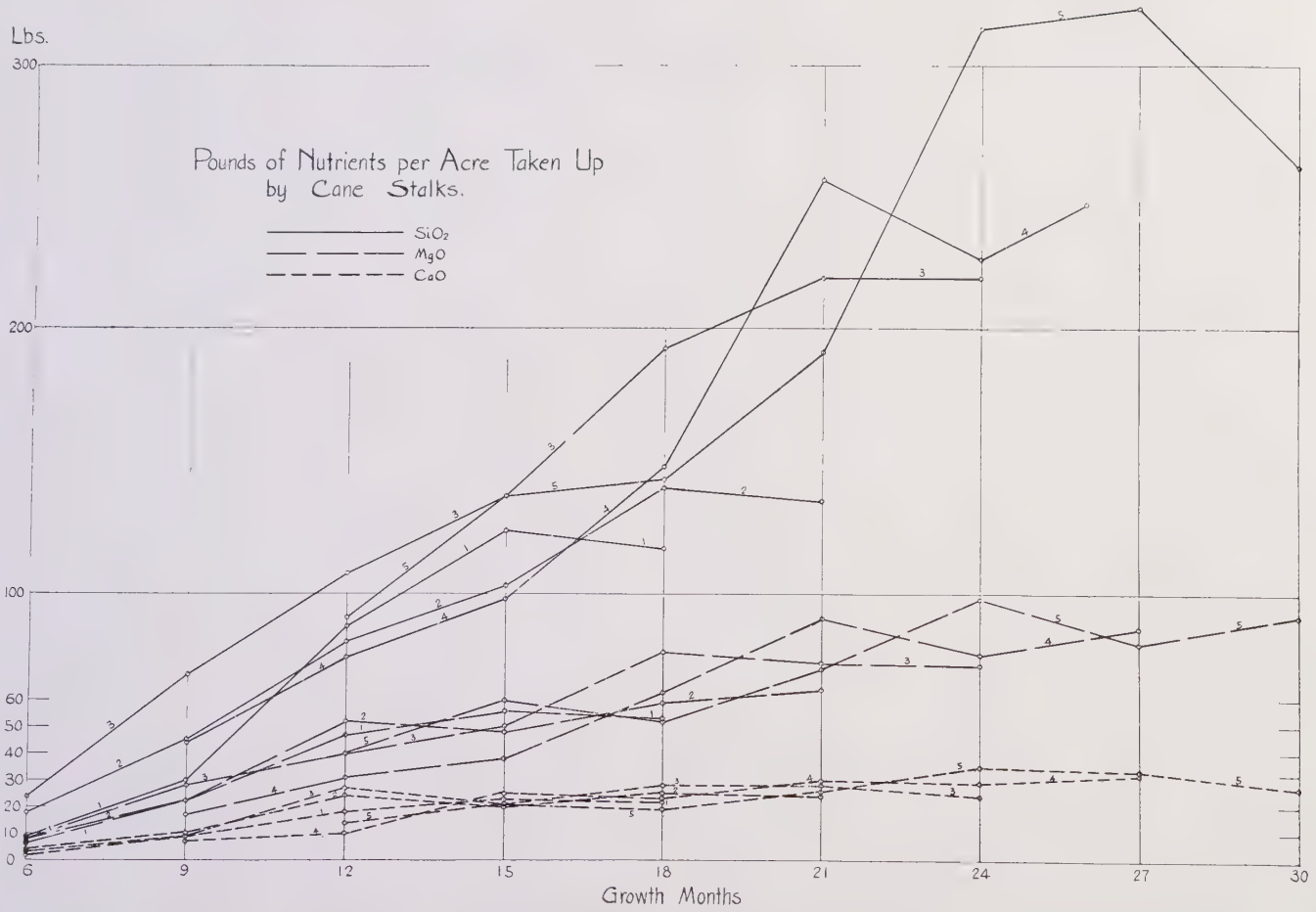

Lbs.
300
200
100
60
50
40
30
20
10
0
Pounds of Nutrients per Acre Taken Up
by Cane Stalks.
SiO2
MgO
CaO
6
9
12
15
18
21
24
27
30
Growth Months

Fig. 7

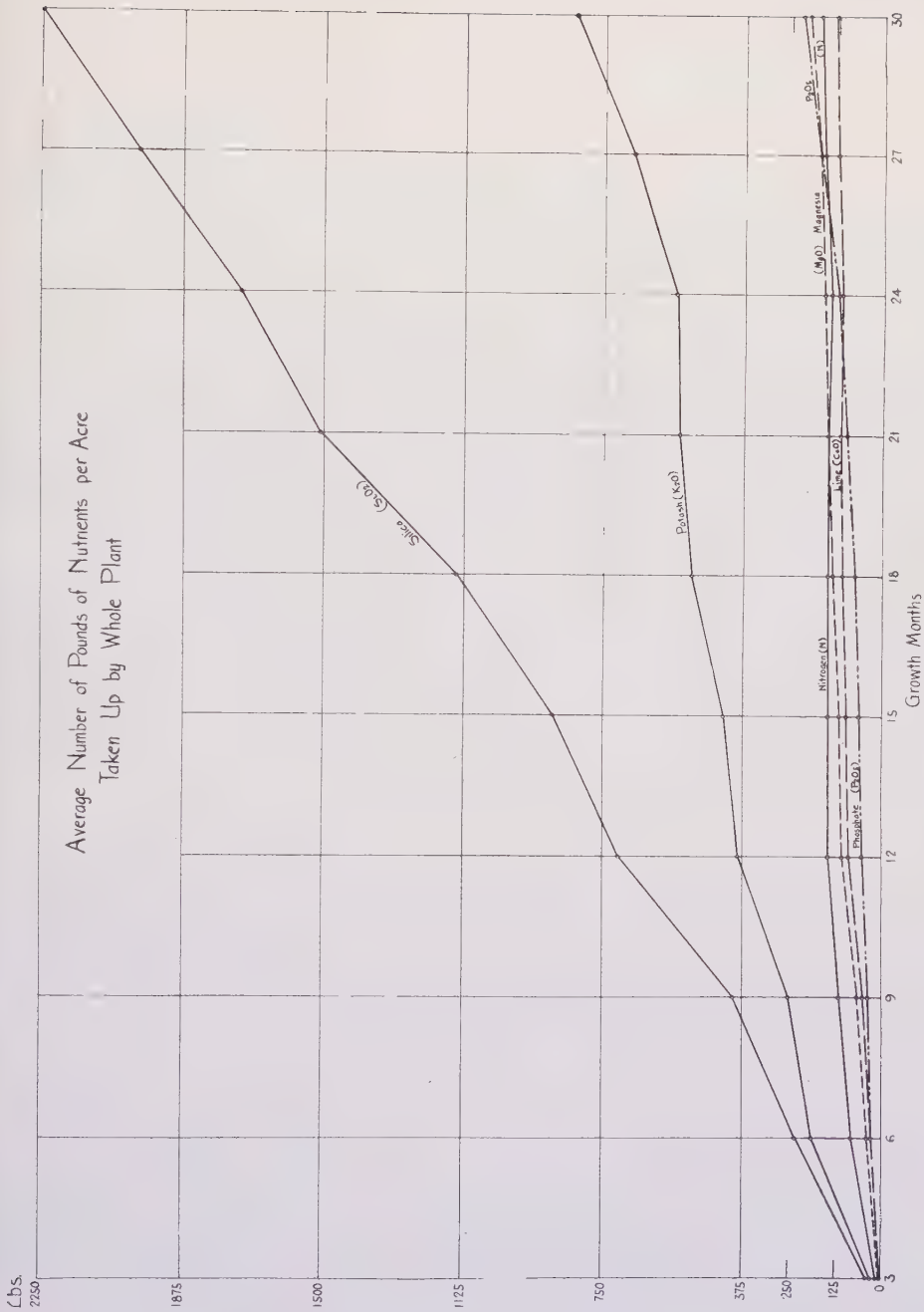
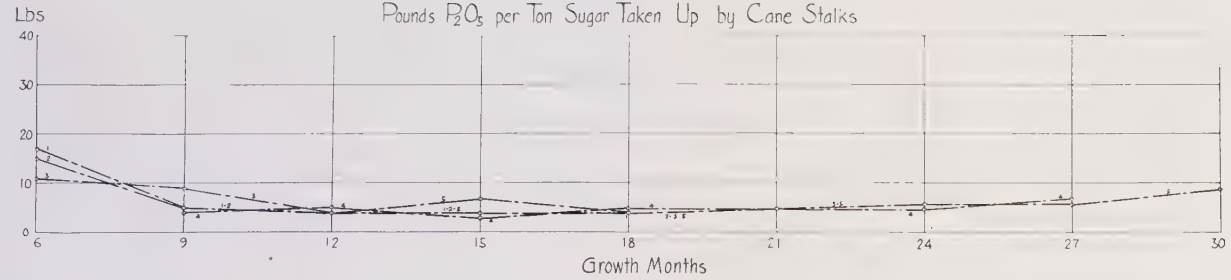
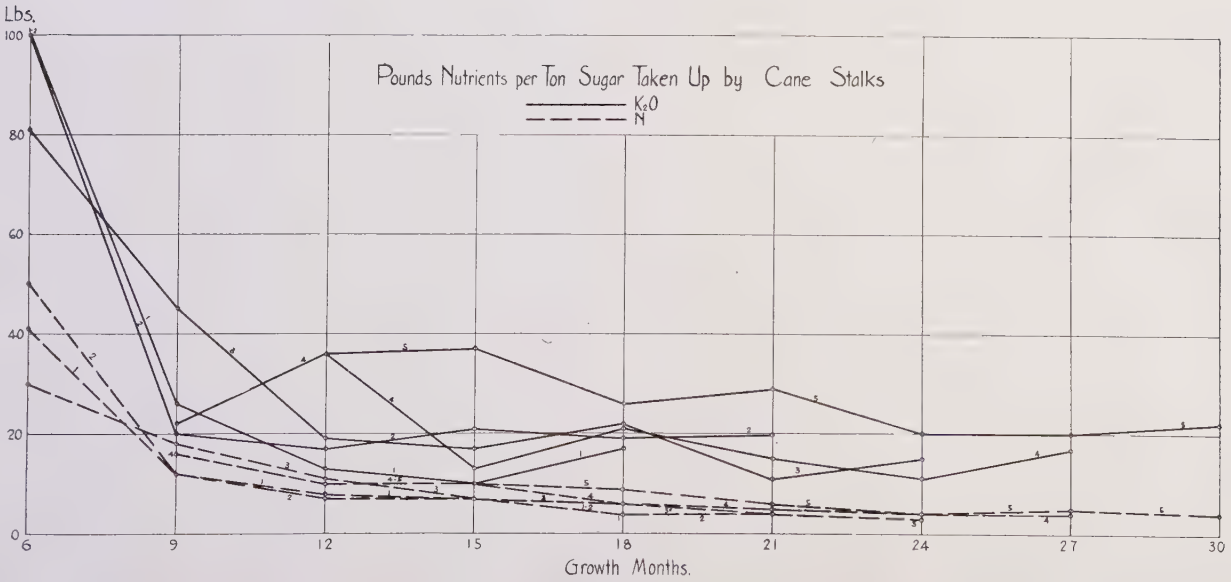

Average Number of Pounds of Nutrients per Acre
Taken Up by Whole Plant
Lbs.
2250
1875
1500
1125
750
375
250
125
0
3
6
9
12
15
18
21
24
27
30
Growth Months
Silica (SiO2)
Potash (K2O)
Lime (CaO)
Magnesia (MgO)
P2O5
(N)
Nitrogen (N)
Phosphate (P2O5)

Fig. 8


Lbs
Pounds P_2O_5 per Ton Sugar Taken Up by Cane Stalks
40
30
20
10
0
6
9
12
15
18
21
24
27
30
Growth Months


Lbs.
Pounds Nutrients per Ton Sugar Taken Up by Cane Stalks
K_2O
N
100
80
60
40
20
0
6
9
12
15
18
21
24
27
30
Growth Months.

Figs. 9 and 10

The Determination of Soil Reaction by Hydrogen Electrode

By Ritchie R. Ward

In a paper which appeared in *The Hawaiian Planters' Record* some six years ago, King (1) gave a clear development of the relation between hydrogen ion concentration and the pH of a solution. These terms are coming into steadily increasing use in the literature, and a thorough understanding of their significance is prerequisite to an appreciative reading of this material.

Since the appearance of this paper, the use of the hydrogen electrode for measuring hydrogen ion concentration has become more general. In the present paper, an attempt will be made to show how acidity, and particularly soil reaction, is determined with this apparatus.

In outline, the method consists of setting up a galvanic cell, one of whose electrodes is hydrogen-hydrogen ion, and the other mercury, calomel and chloride ion. When such a cell is constructed, the two electrodes being connected across a liquid junction, an electromotive force will be set up, the value of which depends, among other things, on the concentration of hydrogen ion in contact with the hydrogen electrode. By keeping other variables constant, it is possible to measure the hydrogen ion concentration by measuring the value of the electromotive force of the cell.

It should be emphasized that this electromotive force is the reversible one, set up when the electromotive force of the cell is exactly balanced by a counter electromotive force of external origin, such as from a storage battery. In this way only, may the maximum work of the cell reaction be measured. The value of this maximum work is an entirely different quantity from that produced when the cell reaction is allowed to proceed irreversibly. This will be seen to be analogous to the case of a simple heat engine. Here, too, the maximum work is not measured unless the engine is exactly balanced by an external force. In either case, the measurement must be taken at equilibrium.

In general, any chemical reaction is accompanied by a change of energy. A common example of this effect is the burning of carbon to carbon dioxide with the liberation of heat. Now, by taking into account the amount of heat liberated, and the work done upon the surroundings by such a reaction, it is possible to derive a measure of the tendency of that reaction to take place. Another, and better, measure of this tendency also takes into account the change in so-called entropy* during the reaction. This latter quantity is known as the free energy, or chemical potential, and is analogous to fluid head or electrical voltage. In fact, the free energy may be used to calculate the electrode potential of a reaction in volts, and this is often done.

Returning to the consideration of the cell, which may be represented thus:

$$Hg, HgCl(s), Cl^-(N/10) \parallel KCl(sat.) \parallel H^+, H_2(g), Pt,$$

* The concept of entropy involves many ramifications, but for the purpose of the present discussion, it may be considered as that portion of the energy of a substance which is unavailable for the performance of useful work.

it will be seen that the following reactions occur:

(a) $Hg + Cl^- = HgCl + E^-$,*
(b) $H^+ + E^- = \frac{1}{2} H_2(g)$.

Each of these reactions has a definite potential in the sense discussed above, which is expressible in volts. This value will, of course, vary as the concentration of the ions H^+ and Cl^- vary.

For any reaction, such as

$$lL + mM + \ldots = rR + sS + \ldots + NE$$

the value of the electromotive force of the reaction may be calculated from the equation:

$$E = E^\circ - \frac{RT}{NF} \ln \frac{a_R^r \cdot a_S^s}{a_L^l \cdot a_M^m} \qquad (I)$$

where E° is the electrode potential when all the substances are at unit activity, R is the gas constant expressed in calories per degree, T is the absolute temperature, N is the number of equivalents, and F is the value of the Faraday, expressed in calories per volt equivalent. The natural logarithm is represented by ln, and a† is the activity.

Applying this equation to reaction (*a*), we get

$$E = E^\circ - \frac{RT}{F} \ln \frac{1}{aCl^-} \qquad (II)$$

From the work of Lewis and Randall (*2*), $E^\circ = -.2700$ volts. The same workers have determined the activity of chloride ion from freezing point data, and have found it to be 0.0794 in tenth normal solution. Either the tenth normal or the normal calomel electrode may be employed, but inasmuch as the tenth normal one is in more general use, it will be the only one discussed here. Substituting these values in the equation:

$$E = -0.2700 - \frac{RT}{F} \ln \frac{1}{0.0794}$$

$$E = -0.3351$$

This, then, is the potential of the tenth normal calomel electrode at 25° C.

For reaction (*b*)

$$E = E^\circ - \frac{RT}{F} \ln \frac{(H_2)^{\frac{1}{2}}}{(H^+)} \qquad (III)$$

---

* The symbol E^- represents an electron. A reaction in which an electron is gained is a reduction, and, conversely, an oxidation.

† The activity may be regarded as a corrected concentration; in fact, it is equal to the concentration in an infinitely dilute solution. Its value is determined by measurements of the freezing point lowering or boiling point raising of solutions.

Here, E° has, by international agreement, been arbitrarily defined as zero, the activity of the hydrogen gas is taken as the pressure, and in very dilute solutions, the activity of the hydrogen ion is equal to its concentration. When substituting numerical values in the equation:

$$E = 0 - 0.05915 \log \frac{1}{(H^+)}$$

Adding (1) and (2), there appears for the reaction

$$Hg(l) + H^+ + Cl^- = HgCl(s) + \tfrac{1}{2} H_2(g),$$

$$E = -0.3351 - 0.05915 \log \frac{1}{(H^+)}$$

But by definition, $pH = \log \frac{1}{(H^+)}$, whence

$$pH = -\left(\frac{E + 0.3351}{0.05915}\right)$$

It may be noted that the value of E for the above reaction will be negative, since the reaction proceeds spontaneously to the left. As will be seen from the equation, the only measurement necessary to a determination of the pH of a solution is the voltage E, but the dependence of the entire procedure upon the results of previous workers in pure science is quite obvious.

The value of the electromotive force of this cell may, however, be affected in a number of ways other than those discussed above.

It will be noted that there are three liquid junction potentials as the cell is ordinarily set up. These are all potassium chloride junctions, and it is rather important to see why they are so small as to be negligible for all practical purposes.

In general, liquid junction potentials are due to the difference in ionic mobilities of the anions and cations in a solution. Suppose a long tube filled with dilute hydrochloric acid is under a uniform potential gradient of one volt per centimeter. It has been found that the hydrogen ion moves with a velocity of 32.50×10^{-4} centimeters per second in such a tube, and the chloride ion moves with a velocity of 6.78×10^{-4} centimeters per second. The relative velocities of free movement of these ions will be in much the same ratio.

Now if a solution of hydrochloric acid is in contact with pure water at an imaginary interface, both hydrogen ions and chloride ions will tend to diffuse from the solution across the boundary into the water. But the hydrogen ions move about five times as fast as the chloride ions, so that there will eventually be more positively charged ions on the water side of the boundary, and more negatively charged ions on the hydrochloric acid side. An electromotive force corresponding to this distribution of charges will be set up across the junction.

The same general considerations apply to two solutions of different concentrations. This is the type of liquid junction commonly met with in cells for electrode

potential measurements. In such cases it is possible to calculate the potential across a liquid junction from ionic mobility figures and apply the correction so derived. Sometimes, also, the effect is greatly reduced by construction of flowing junctions, so that practically no diffusion can occur.

It would be simpler and more satisfactory if a solute could be found whose anions and cations moved at the same rate. In such a case no accumulation of charges would occur on either side of a boundary, and consequently no electromotive force would be set up. This is very nearly true for potassium chloride, the absolute velocity of potassium ion being 6.70×10^{-4} centimeters per second, and that of chloride ion being 6.78×10^{-4}. Accordingly, potassium chloride is generally used for liquid junctions of this kind.

It will be recalled that in applying Equation III, it was assumed that the hydrogen was at atmospheric pressure. This is not quite true, since the solution exerts a partial pressure, and the hydrogen is below atmospheric by a corresponding amount.

As an example, the effect of pure water vapor on the pH may be calculated. The vapor pressure of water at 25° C., is 25 mm., whence the actual hydrogen pressure over the solution is (760-25)/760, or 0.967 atmospheres. Suppose that the voltage read on the potentiometer is —0.7491, which is the value for pH = 7.0 when no correction is made for the reduced hydrogen pressure. Using the equation without transposition:

$$-0.7491 = E = -0.3351 - 0.05915\ (.967)^{\frac{1}{2}}\ pH$$

so that pH = 7.10.

It will then be seen that the vapor pressure of the water affects the result by 0.10 pH units.

In determining the pH on soils, the reaction will not be affected to as great an extent as indicated above, since the presence of a solute lowers the vapor pressure of the water.

In this connection it may be pointed out that the solution must be completely reduced so that it will support one atmosphere of hydrogen, before the voltage is read.

In the case of a soil which is high in carbonates, and is otherwise poorly buffered, the following equilibrium is established:

$$2H^+ + CO_3^= = H^+ + HCO_3^- = H_2CO_3 = H_2O + CO_2$$

When hydrogen is bubbled through the solution, carbon dioxide is carried off with it, and the equilibrium is shifted to the right, according to le Chatelier's rule. This will continue until the reaction comes practically to completion, and inasmuch as hydrogen ion is involved in the equilibrium, the pH will also change. The two readings obtained after fifteen minutes and after an hour's bubbling with hydrogen may differ widely.

In order to avoid this effect, the determination may be made in special apparatus in which the hydrogen is brought into equilibrium with the solution without bubbling, and the correction for the partial pressure of the carbon dioxide applied.

This is done in a manner exactly similar to the correction for the partial pressure of water vapor cited above.

It is also possible to determine the partial pressure of the carbon dioxide from the solution, and use a corresponding mixture of hydrogen and carbon dioxide for bubbling through the regular Hildebrand electrode. In this way the equilibrium is not affected by the bubbling of gas through the solution.

Finally, the effect of temperature differences on the electromotive force of the cell may be calculated. The Gibbs-Helmholtz equation gives this effect:

$$E + \frac{\triangle H}{NF} = T \frac{dE}{dT}$$

Here $\triangle H$ is the molal heat of the cell reaction, which may be obtained by measurements with a calorimeter, or more accurately, by calculation from electrode potential data. The other symbols have the same significance as noted above, while dE/dT is the differential coefficient of the voltage with respect to temperature.

Lewis and Randall give $\triangle H = 8291$ calories, and using the value —0.7491 volts for E, it follows that

$$\frac{dE}{dT} = \frac{-0.7491 + \frac{8291}{23074}}{298.1}$$

at a temperature of 25° C. Whence,

$$\frac{dE}{dT} = -0.00131,$$

so that the electromotive force of the cell decreases 1.31 millivolts for each degree rise in temperature. This corresponds to a change in pH of about one-tenth of a point for a five-degree temperature increment.

Thus, it is apparent that while many factors influence the electromotive force of a galvanic cell such as is used in determining the hydrogen ion concentration of solutions, all those which are of significant influence may be held constant. There then remain but two variables, the independent variable corresponding to the pH of the solution, and the dependent variable corresponding to the voltage. When one is measured, the other may be certainly known, for any set of conditions.

The process may be thought of as being much the same as that employed in weighing with a sensitive balance. In the latter case, two gravitational forces are balanced, and the known magnitude of one gives the magnitude of the other. So, similarly, in the cell, two opposing electrical forces are delicately balanced against each other, and precisely analogous conditions obtain.

Summary

1. The reaction which occurs in a typical cell used in determining pH has been discussed.

2. Equations have been presented for calculating the electromotive force of such a cell.

3. It has been shown how the voltage of the cell is affected by changes in temperature, pressure and composition.

LITERATURE CITED

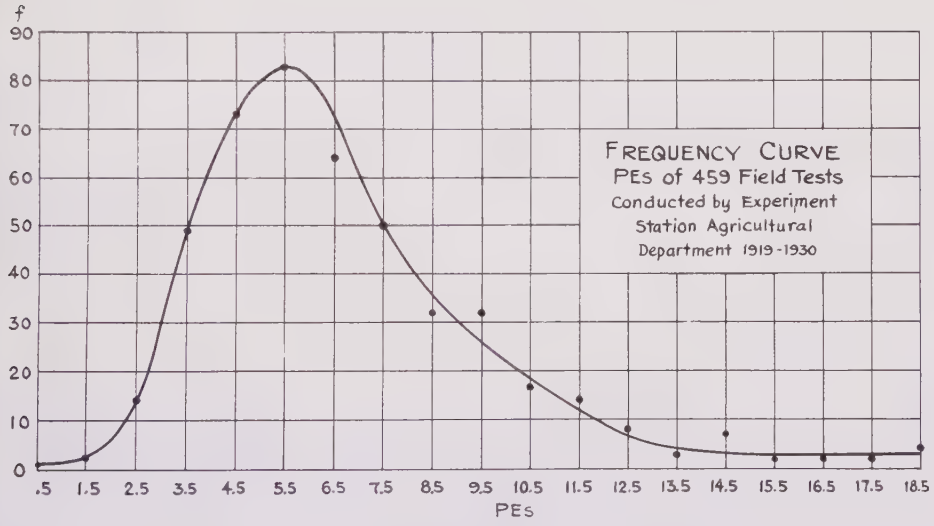
1 King, R. H. 1924. A discussion of the meaning of the terms hydrogen ion concentration and pH values of solutions. Hawaiian Planters' Record, Vol. XXVIII, pp 120 128.

2. Lewis, Gilbert N., and Randall, Merle. 1923. Thermodynamics and the free energy of chemical substances. McGraw-Hill Book Co.

A Study of the Probable Error of a Single Plot from Field Tests with Sugar Cane in Hawaii

By Ralph J. Borden

During the past ten years, a considerable amount of valuable data concerned with field experiments that have been conducted by the agricultural department of the Experiment Station, H. S. P. A., have been collected. When Dr. H. H. Love, of Cornell University, visited us in the fall of 1929, he suggested that a critical statistical examination of this mass of data might be very enlightening to our agricultural workers, and that undoubtedly it would help us to see where our field experimental technique might be improved. Consequently, plans were made to study the available data and the presentation that follows summarizes the results of what was found.



Method

A total of 459 field tests furnished the basic information. In each test, the individual plot yields were recorded and then reduced to percentages of their mean or "Treatment" yield, in order that we might have yield figures for all plots in the test upon a common basis for our statistical examination. The accompanying table shows the form on which our data were recorded and the manner in which our calculations were made. It will be noted that the percentage PEs for each "Treatment" was calculated, as well as the per cent PEs for the whole experiment. This served as a check on our calculations, and also furnished the data for studies concerned with various "Treatments".

When plotted for a frequency curve (see figure) the PEs for our tests show a skewed type of curve, which is not uncommon when results of field tests are thus

plotted, and it is not surprising to find a considerably greater number of tests that deviate from a normal distribution curve in the upper range than at the lower points. (These large deviations are no doubt due to our extreme variations in soil fertility, and include some rather large errors unknowingly introduced through difficult harvesting operations. From this frequency curve, and using the formula suggested by J. W. Mellor in his "Higher Mathematics for Students of Chemistry and Physics," for the rejection of data supposedly due to suspected observations, it was calculated that any experiment that carried a PEs of 16 per cent or more might be rejected. This resulted in the rejection of eight tests, and consequently our studies were based on the 451 cases that remained.

Plantation, Hilo Sugar Co. **Experiment No.** 37FN. **Crop Year** 1930. **Field** 51, Wainaku. **Elevation**, 400 feet. **Variety**, Yellow Caledonia. **Size of Plot**, .1 acre. **Plant or Ratoon**, plant. **Date Harvested**, Feb. 1, 1930. **Age at Harvest**, 21 months. **No. of Lines**, 6. **Length of Lines**, 132 feet. **Guard rows eliminated**, 2. **Object**: Forms of Nitrogen.

Series	No. of Plots	Treatment	Total Plant Food N	P_2O_5	K_2O
A	7	N from Nitrate of Soda	226	48	240
B	7	N from Leunasaltpeter	226	48	240

Series	Plot No.	Area Acre	Yield T. C. A.	Mean Yield	Yield Per Cent of Mean	D	D^2
A	1	.066	89.4	...	100.9	+ .9	.81
	3	.066	88.6	...	100.	.....	0.
	5	.066	94.0	...	106.0	+ 6.0	36.00
	7	.066	86.2	...	97.2	— 2.8	7.84
	9	.066	85.7	...	96.7	— 3.3	10.89
	11	.066	91.5	...	103.2	+ 3.2	10.24
	13	.066	85.1	88.6	96.0	— 4.0	16.00
						+10.1	81.78
						—10.1	
B	2	.066	93.7	...	109.9	+ 9.9	98.01
	4	.066	85.9	...	100.8	+ .8	.64
	6	.066	84.4	...	99.0	— 1.0	1.00
	8	.066	82.2	...	96.4	— 3.6	12.96
	10	.066	89.1	...	104.5	+ 4.5	20.25
	12	.066	78.2	...	91.7	— 8.3	68.89
	14	.066	83.2	85.2	97.6	— 2.4	5.76
						+15.2	207.51
						—15.3	

For Treatment A:

$$\text{S. D.} = \frac{\Sigma D^2}{N-1}\sqrt{\quad} = \sqrt{\frac{81.78}{6}}$$

$$= 3.69\%$$

$$\text{PEs} = .6745 \text{ S. D.}$$

$$= 2.49\%$$

For Treatment B:

$$\text{S. D.} = \sqrt{\frac{207.51}{6}}$$

$$= 5.88\%$$

$$\text{PEs} = 3.97\%$$

For Test Area:

$$\text{S. D.} = \sqrt{\frac{81.78 + 207.51}{13}} = \sqrt{\frac{289.29}{13}} = 4.72$$

$$\text{PEs} = .6745 \text{ S. D.} = 3.18 \text{ per cent}$$

Detail

The study aimed to answer a number of questions.

(a) *What is the probable error of a single plot (PEs) for cane field experiments as conducted in Hawaii?*

The answer to this question should indicate the variation that exists in our experimental areas and the degree of refinement of our experimental technique. It should give us some idea of how we may modify the customary manner of laying out and conducting field tests, in order to eliminate or lessen those conditions which often make it difficult to interpret their results.

Due to the varied conditions under which our cane field tests are carried on, this question was subdivided in order to note the effect of the two greatest differences, irrigated vs. non-irrigated cane, upon the PEs in tests conducted thereunder.

The probable error for a single plot, when all 12,271 plots contained in our 451 tests are considered, was found to be 6.6 per cent; of the 3,569 plots contained in 133 tests on unirrigated cane, the PEs is 6.8 per cent; of the 8,702 plots in the 318 tests conducted on irrigated lands, the PEs is 6.5 per cent. From this it would appear that the variation which exists in our field experiments, whether conducted on irrigated or upon unirrigated areas, is very nearly equal. An analysis of the conditions which are the greatest factors affecting our experimental error, tends to show that while differences in soil moisture content on irrigated lands may cause a large error which is not a factor on unirrigated cane, greater soil variation exists on the shallow upland areas of the non-irrigated plantations than on the deeper more fertile soils of the other group. Presumably, therefore, the adverse effect of one major factor upon the variability within our experiment is offset by the advantage of the other factor.

(b) *Does the variation within our test area, as indicated by the PEs, change with the age of the field?*

This question aimed to secure confirmation or refutation for various expressions of opinion regarding the effect of stand as a factor of variability in field tests with cane.

The problem was attacked from two angles:

1. The PEs for both irrigated and non-irrigated cane of all plant, first ratoon, second ratoon, and third ratoon (plus a few 4th, 5th and 6th) crops was calculated. The results are summarized as follows:

	Non-Irrigated Cane		Irrigated Cane	
Age of Field	No. of Tests	PEs	No. of Tests	PEs
Plant	60	7.0	112	6.3
First Ratoon	38	7.8	102	6.8
Second Ratoon	15	5.9	60	6.8
Third Ratoon +	20	6.5	44	5.9

It is rather difficult to draw conclusions from these figures. We have too few cases of second and third ratoon crops on non-irrigated areas to warrant comparison with the plant crop. In the irrigated group, the slightly lower PEs for

third ratoon + crops is due to the fact that 26 of these 44 tests were at the Waipio substation where the PEs for all tests is 4.8 per cent.

At Waipio:

223 plots of plant cane have a PEs of 4.9 per cent
167 plots of 1st ratoon have a PEs of 3.9 per cent
169 plots of 2nd ratoon have a PEs of 3.6 per cent
206 plots of 3rd ratoon have a PEs of 4.6 per cent
352 plots of 4th ratoon have a PEs of 4.8 per cent
231 plots of 5th ratoon have a PEs of 5.6 per cent

At Pioneer:

928 plots of plant cane have a PEs of 6.3 per cent
1010 plots of 1st rtaoon cane have a PEs of 6.8 per cent
806 plots of 2nd ratoon cane have a PEs of 6.9 per cent
141 plots of 3rd ratoon cane have a PEs of 6.3 per cent

If the variability of ratoons at Waipio seems to decrease on the early ratoons, then the situation seems reversed at Pioneer. Hence no general assumption can be made from the data available.

(2) Although we have an insufficiency of data, from tests which have been repeated on the same plots through successive crops, to give us over-confidence in a feeling that the cane plant has a remarkable aptitude for adjusting its stand to the conditions it finds itself growing in, there is some indication that this may be the case, and that the variation that exists in our test areas does not materially change from crop to crop as a result of a change in stand.

In that number of repeated tests which our data included we found the following:

(a) The PEs of the first repetition greater than in the original test in 57 cases, and less than in the original test in 42 cases.

(b) The PEs of the second repetition greater than in the first repetition in 20 cases and less in 21 cases; greater than in the original test in 22 cases and less than the original in 19.

(c) The PEs of the third repetition greater than in second in 4 cases and less in 3; greater than the first repetition in 3 and less in 3 cases; greater than in the original test in 3 cases, and less than in the original in 3 cases also.

Individual plantation data show a similar tendency.

At Waipio, we have the following:

Twelve tests, repeated, show a higher PEs on the succeeding than on the original test; thirteen tests show a lower PEs after the original test.

At Pioneer, 32 tests show a higher PEs on ratoons than on plant, while 27 show up higher on plant than on ratoons.

At Koloa, 5 out of 10 tests which were repeated have a higher PEs in the original than in the succeeding crop.

(c) *How does the size of the individual plot affect the probable error of the experiment?*

We find advocates of small plots and advocates of large ones. Have our experimental data indicated what size of plot is best suited for accuracy?

The standard size plot for unirrigated cane has generally been accepted as one-tenth acre, while the conventional watercourse plot varying from slightly under to slightly over a tenth acre has been the unit used on irrigated lands. We find that 85 per cent of our tests have used these unit plot sizes, only 9 per cent having used a smaller and 6 per cent a greater size. Hence our data on this question are too meager for statistical study.

We have, however, enumerated below 5 cases where the data within each case are quite comparable and have a bearing on this question of plot size. These are offered as a matter of interest and for record.

Plantation	Field	Year	Exp. No.	No. of Plots	Plot Size	Total Test Area	PEs
(1) Paauhau	18	1921	10	32	.25 ac.	8 ac.	3.9
"	18	1921	11	18	.1 ac.	1.8 ac.	6.6
(2) Hakalau	10	1919	8	24	.1 ac.	2.4 ac.	5.0
"	10	1919	3B	36	.05 ac.	1.8 ac.	7.3
"	10	1919	7	48	.1 ac.	4.8 ac.	9.2
"	10	1919	9	72	.05 ac.	3.6 ac.	12.4
(3) Kilauea	37	1924	51	15	.07 ac.	1.1 ac.	8.2
"	37	1924	30	15	.1 ac.	1.5 ac.	12.7
"	37	1924	31	18	.1 ac.	1.8 ac.	14.5
"	37	1924	28	32	.1 ac.	3.2 ac.	10.7
(4) Pioneer	E2	1929	71	20	4 we	80 we	5.0
"	E2	1929	49	24	1 we	24 we	9.4
"	E2	1929	50	20	1 we	20 we	10.9
"	E2	1929	47	18	1 we	18 we	6.4
"	E2	1929	48	15	1 we	15 we	9.6

(5) At the Maui Agricultural Company the 10 tests which were studied showed a PEs of 4.8 per cent. Of these 10 tests, 4 used level ditch plots (area 1.0 + acres) and the PEs was 3.9 per cent; 6 used single watercourse plots and these had a PEs of 5.4 per cent.

(d) *What effect has the number of replications on the size of the PEs for our cane field tests?*

Theoretically, statistical measurements tell us that a reduction in error may be expected to occur in direct proportion to the square root of the number of samples taken. Because of the fact that when we increase the number of replications (samples) in our field tests, we must move into an increased area and hence possibly include new variations, this expected reduction in our experimental error does not always take place at any proportional rate.

Analysis of our complete data which concerns this question follows:

In 42 tests with 4 or less replications, the PEs was 6.5 per cent
In 68 tests with 5 replications, the PEs was 6.7 per cent
In 111 tests with 6 replications, the PEs was 5.9 per cent
In 80 tests with 7 replications, the PEs was 6.4 per cent
—6.3 per cent

In 66 tests with 8 replications, the PEs was 6.6 per cent
In 17 tests with 9 replications, the PEs was 6.8 per cent
In 14 tests with 10 replications, the PEs was 7.3 per cent
—6.9 per cent

In 53 tests with more than 10 replications, the PEs was 7.7 per cent

At Waipio:

8 tests with 4 or less replications had a PEs of 3.2 per cent
17 tests with 5 to 7 replications had a PEs of 4.3 per cent
9 tests with 8 to 10 replications had a PEs of 4.7 per cent
10 tests with more than 10 replications had a PEs of 6.4 per cent

At Pioneer:

23 tests with 5 replications had a PEs of 6.3 per cent
40 tests with 6 replications had a PEs of 6.6 per cent
29 tests with 7 replications had a PEs of 6.4 per cent
} —6.4 per cent
13 tests with 8 to 10 replications had a PEs of 6.1 per cent
9 tests with more than 10 replications had a PEs of 8.9 per cent

(e) *Does the size of the total experimental area affect the PEs?*

We have assumed that under the widely varying soil conditions existent in our fields, the variation between plots established therein would be increased as our total area was enlarged. Our complete data indicate that there is a tendency for this to happen.

130 tests, in which the total area was under 2 acres, had a PEs of 6.4 per cent.
193 tests, in which the total area was from 2 to 3 acres had a PEs of 6.4 per cent.
128 tests, in which the total area was over 3 acres had a PEs of 7.0 per cent.

At Pioneer:

38 tests, in which the total area was under 2 acres, had a PEs of 6.4 per cent.
69 tests, in which the total area was from 2 to 3 acres, had a PEs of 6.9 per cent.
9 tests, in which the total area was over 3 acres, had a PEs of 7.7 per cent.

At Koloa:

8 tests in which the total area was under 2 acres had a PEs of 6.4 per cent.
10 tests in which the total area was from 2 to 3 acres had a PEs of 8.5 per cent.
4 tests in which the total area was over 3 acres had a PEs of 11.7 per cent.

(f) *What is the relation between the total number of plots and the probable error of a single plot?*

138 tests with less than 20 plots per test show a PEs of 6.3 per cent.
212 tests with 20 to 29 plots per test show a PEs of 6.4 per cent.
55 tests with 30 to 39 plots per test show a PEs of 6.7 per cent.
32 tests with 40 to 52 plots per test show a PEs of 7.2 per cent.
14 tests with over 55 plots per test show a PEs of 9.0 per cent.

From this, it would appear that there is perhaps a slight increase in the variability within our test area as the number of plots is increased.

(g) *Is there any relationship between the number of variates or treatments in our test and the PEs?*

73 tests carrying 2 variates have a PEs of 6.6 per cent.
116 tests carrying 3 variates have a PEs of 6.3 per cent.
201 tests carrying 4 variates have a PEs of 6.5 per cent.
33 tests carrying 5 variates have a PEs of 7.0 per cent.
28 tests carrying 6 or more variates have a PEs of 8.6 per cent.

Hence, it would seem that the number of variates per test has little influence on the probable error of a single plot until our tests begin to carry six or more different treatments, when it appears that the increased number of variables has probably increased the total experimental area and hence widened the variability between plots therein.

(h) *What is the effect of the cane yield upon the PEs?*

The following table shows the frequencies with which the probable errors of single plots have occurred in fields of varying cane tonnages:

FREQUENCIES OF PEs (IN PER CENT) AS RELATED TO CANE TONNAGE

Av. Cane Tonnage	Under 3 Per cent.	3.1 to 5 Per cent.	5.1 to 7 Per cent.	7.1 to 9 Per cent.	9.1 to 11 Per cent.	11.1 to 13 Per cent.	13.1 to 15 Per cent.	Over 15 Per cent.	Total Tests
20 to 40	3	4	27	24	13	11	9	6	97
40 to 60	2	32	46	36	24	6	0	4	150
60 to 80	3	53	44	18	7	5	1	0	131
80 to 100	6	24	20	2	6	0	0	0	58
100 to 120	3	11	8	1	0	0	0	0	23
Totals	17	124	145	81	50	22	10	10	459

From this table, it is quite apparent that the greater variations within our field tests, as indicated by the larger PEs per cent figures, are in the poorer producing areas, and that as our yields are increased the PEs tends materially to be improved.

Roughly figured, we note the following:

In 30-ton cane, only one-third of the tests have a PEs under 7 per cent, and less than one-tenth of them have a PEs under 5 per cent.

In 50-ton cane, about one-half of the tests have a PEs under 7 per cent, and one-fifth are under 5 per cent.

In 70-ton cane, three-fourths of the tests are under 7 per cent and two-fifths under 5 per cent.

In 90-ton cane, seven-eighths of the tests have errors attached to single plots of less than 7 per cent, and on one-half of the tests observed on fields producing at this rate, the PEs is under 5 per cent.

In 110-ton cane, practically no test has a PEs greater than 7 per cent. Sixty per cent of our tests on these areas of high yields carry errors of single plots which are under 5 per cent.

(i) *What is the effect of plant food upon the probable error of a single plot or areas receiving different kinds and amounts of food?*

This question aimed to find out whether the variation between plots in cane that was amply supplied with plant food was less than the variation occurring in areas where the supply of some food material might be scanty.

The results are summarized below. They indicate that well fed cane carries a lower PEs than cane which has less food. From which it is not unreasonable to believe that an ample supply of plant food will do much to offset the natural soil plant food deficiencies which are perhaps responsible for much of the variation between plots in our experimental areas.

EFFECT OF PLANT FOODS ON THE PEs OF A SERIES OF PLOTS RECEIVING SPECIFIC PLANT FOOD TREATMENTS

No. of Comparable Series	Treatments Compared	Number of Cases Showing		
		No Change in PEs (within .1 Per cent)	Lower PEs with Increased Food	Higher PEs with Increased Food
26	No Fertilizer vs. N[1]	1	23	2
67	N vs. NP	1	42	24
72	N vs. NK	2	34	36
69	N vs. NPK	2	39	28
65	NP vs. NPK	1	24	40
67	NK vs. NPK	1	36	30
5	PK vs. NPK	0	5	0
31	No P vs. P[2]	0	19	12
32	No K vs. K[2]	1	20	11
48	Less than 100 lbs. N vs. 150 lbs. N[3]	1	35	12
70	150 lbs. N vs. 200 lbs. N	3	33	34
55	200 lbs. N vs. 250 lbs. N	0	26	29
50	250 lbs. N vs. 300 to 350 lbs. N	5	21	24
36	No P vs. 60 lbs. P	1	20	15
22	60 lbs. P vs. 120 lbs. P	2	9	11
23	120 lbs. P vs. 180 to 200 lbs. P	..	13	10
21	200 lbs. P vs. 300 lbs. P	..	8	13
39	No K vs. 60 lbs. K	..	19	20
25	60 lbs. K vs. 120 lbs. K	2	16	7
35	120 lbs. K vs. 180 lbs. K	..	16	19
26	200 lbs. K vs. 300 lbs. K	1	10	16

(j) *Is the PEs in our experimental fields influenced by the elevation of the area above sea level?*

The factors which complicate an answer to this question are too numerous to enable us to make use of the limited amount of data available. As a matter of interest, however, the tests which were conducted at Pioneer when arranged according to field elevation show the following:

27 tests conducted below 300′ elevation have a PEs of 5.7 per cent.
36 tests conducted between 300′ and 600′ elevation have a PEs of 7.0 per cent.
35 tests conducted between 600′ and 900′ elevation have a PEs of 6.6 per cent.
11 tests conducted above 900′ elevation have a PEs of 8.1 per cent.

[1] 150 lbs., [2] 250 lbs., [3] Amounts that follow are approximate.

A factor which greatly complicates any analysis of these figures from Pioneer, however, is that cane from the upper elevation fields is flumed from the plots before weighing, and the influence of this factor may be better understood from the following:

Thirty-nine tests in which cane was flumed before weighing show a PEs of 7.7 per cent; half of them carrying errors over 8 per cent. Against this, we have 76 tests which were loaded directly onto cars in the field, which have a PEs of 6.0 per cent, with only one-tenth of same having errors greater than 8 per cent.

(k) *Will an analysis of our PEs data assist us to locate our field tests so that introduced variates may have fair comparisons?*

The data in the following table should help us to answer this question, if we are right in assuming that a low PEs indicates a lack of extreme variability in our test area. Where several tests that have been harvested in the same locality carry a PEs below 7 per cent we have a fairly good indication that the natural conditions there are quite similar, and it should be a good place for our field experiment:

SOME PEs OF TESTS LOCATED IN SPECIFIC FIELDS

			No. of Tests with PEs Per Cent				
Plantation	Field	Total Tests	Under 5	5–7	7–9	9–12	Over 12
Paauhau	18	2	1	1	..	..	..
"	4	2	..	2	..	..	..
"	2	2	..	2	..	..	..
Lihue	40	7	3	4	..	..	..
Makee	13	2	1	..	..	..	..
"	1	1	2	..	..	..	..
H. C. & S. Co.	D Co. 3	3	3	..	..	..	..
"	12	2	2	..	..	..	..
Maui Agr. Co.	61	2	2	..	..	..	..
Pioneer	32	12	7	3	2	..	..
"	B4	10	5	5	..	..	..
"	33	2	2	..	..	..	..
Honomu	6B	4	1	3	..	..	..
Waipio	V	8	8	..	..	..	..
"	B	3	3	..	..	..	..
Waialua	Gay	3	3	..	..	..	..
"	Mill	5	2	3	..	..	..
Koloa	52	6	4	1	1	..	..
Hamakua	19	4	..	1	2	1	..
Pioneer	B6L	12	1	3	4	4	..
"	LA7	11	2	3	1	5	..
"	E 2	8	1	2	1	4	..
Union	Kah 37	2	..	..	..	..	2
Hilo	10	5	..	1	2	1	1
Kilauea	25	2	..	..	..	..	2
Koloa	51	8	..	2	2	2	2

When several tests in a field show a particularly high PEs we must not be too quick to condemn such field for experimental work. The PEs is affected by factors other than soil variation, and a careful analysis of any test carrying a high

probable error will frequently reveal discrepancies or mistakes which are not due to chance soil variation alone, and which may be rectified so that the true variability of the area in question and its adaptability for field testing can be ascertained.

Summary

A study of the probable error of a single plot for sugar cane field experiments was made from the yields of 12,271 plots harvested in 451 field tests conducted by the Station's agricultural department throughout the Islands during the last ten years.

The probable error for a single plot was found to be 6.6 per cent, with no significant difference between the error from irrigated and non-irrigated areas.

The data warrant no general assumption that the probable error is influenced by the age of the field since last planting. This issue is evidently purely a localized one.

Insufficient data make it impossible to determine the relation between size of plot and size of error. There is some indication that plots somewhat larger than those ordinarily used may carry a lower probable error.

Due to the environmental variability that exists, an increase in the number of replications has not resulted in a proportionate lowering of the probable error. An increase in the size of the total experimental area has generally tended to increase this error.

The number of variates in a test, *per se*, have little if any effect upon the PEs.

The size of the probable error seems to be quite definitely affected by the cane tonnages grown. With high cane yields, we find a considerably greater number of tests carrying low probable errors and few with high errors; on poorer yielding areas, the proportion of tests with high errors is considerably greater.

A relationship is noted between the PEs and the available plant food supply. Plots receiving nitrogen at less than 100 pounds per acre are quite apt to carry larger probable errors than plots of more amply fed cane.

The effect of elevation upon the PEs was so complicated with other factors that no conclusions from the data are justified, but there is some indication that the PEs increases with altitude, probably due to decreasing cane yields.

The study quite definitely located specific fields that are especially adaptable for accurate field test work, as well as it pointed out areas which are unsuitable and upon which the installation of a field experiment would be a questionable procedure.

Some Basic Statistical Data for the Interpretation of Field Experiments at Ewa Plantation Company

By J. D. Bond

Interest in the use of statistical methods as an aid in the interpretation of field experiments has been recently stimulated through the visit of Dr. H. H. Love. Emphasis has been placed particularly on the probable error of a single plot as a prime factor in the expected limits of accuracy of field tests. In order to determine the normal probable error of a single plot under local conditions, as well as the normal curves of error concerned, a portion of the accumulated experimental data of the Ewa Plantation Company over eight crops has been reviewed. These data are derived only from experiments dealing with problems in fertilization and include in the neighborhood of 5000 harvested plots. No attempt has been made in this study to differentiate between the character of the experiment locations as evidenced by plot variation, so that all conditions are represented. We may thus consider the summaries as representative of average conditions.

The experiments concerned have been conducted according to a standard practice which need not be discussed here. In the matter of contiguous plot comparisons, it is our practice in a layout involving only two treatments which are alternated, to compare a treatment plot with the adjacent checks individually. Thus, in a layout as represented below:

Level Ditch

1A	2X	3A	4X	5A	6X

Level Ditch

plot 3A would be compared both with 2X and 4X, and plot 5A with 4X and 6X. Comparisons involving plots 3A and 5A will then total 4. Where check and treatment are not alternated, only one comparison is, of course, available. No comparisons are attempted between plots located in different level ditch areas.

The data have been considered both from the standpoint of the variation about the treatment mean in per cent of the means, and from the standpoint of the variation about mean differences, in original units, from contiguous plot comparisons. The data in both instances have been grouped in classes as indicated in Tables I and II under the heading "Actual Data—Per Cent Frequency." Inasmuch as no omissions were originally attempted in building up these frequency data, it was found advisable to subquently omit from the table those cases, which, from the first completed tabulation or, later, from the partially built frequency variation, extended beyond the initial class showing zero frequency. This was, of course, essential in developing such continuous data as would permit the fitting of the normal curve of error. The effect of these omissions on the final arrangement was very small indeed, the number being usually less than 1 per cent of the total number of individuals. The cases omitted represented such extremes as would

without doubt be omitted in any case in the interpretation of the results of any one experiment.

After these omissions had been effected, the data were re-worked into the final form shown in Tables I and II. It was found, however, that the normal curves of error developed from the calculated standard deviations of the actual data of Tables I and II gave very poor fits, due, presumably, to the preponderance of large variations at the tails of the frequency curves. We proceeded then to determine the modulus of a normal curve of error for every point of Tables I and II including 1 per cent or more of the total number of individuals. Since for every point there are two curves of error which will satisfy the requirements, the modulus of that curve of error giving the standard deviation nearer the standard deviation of the original data, was taken. No corrections were made in the original data for the slight errors involved in grouping or for taking the mean at precisely the mid-point.

The type formula for the normal curve of error is:

$$y = \frac{1}{C\sqrt{\pi}} e^{\frac{-(X - \text{Mean})^2}{C^2}}$$

where Y is the proportional frequency of the variation X; and C is the curve characteristic or modulus.

The arithmetical average of the moduli determined for each point representing 1 per cent or more of the total individuals, then gave us the most probable modulus or the most probable normal curve of error under our conditions.

In two instances in this study, the point considered was found to lie slightly outside the range represented by the normal curve of error at the specific value of X. These points, in so far as the determination of the modulus was concerned were omitted from consideration.

Finally, the normal curves of error for cane, quality ratio, sugar, Brix and purity for both the variation about the mean in per cent of the mean; and for the variation about mean differences in original units from the comparisons of contiguous plots, were plotted in comparison with the actual frequency data and are shown in Figs. 1 to 10. From these data we have the following probable errors of a single plot:

PROBABLE ERROR OF A SINGLE PLOT

	Variation in Per Cent		Variation About Mean Diff.	
	Actual Data	Fitted Curve	Actual Data	Fitted Curve
Cane	±5.68	±4.80	±4.54	±4.09
Q.R.	3.26	2.92	0.27	0.23
Sugar	5.36	4.62	0.60	0.52
Brix	2.00	1.89	0.34	0.29
Purity	0.97	0.83	0.70	0.65

It is at once evident that the probable errors of a single plot calculated from the fitted curves are consistently lower than those obtained from the actual frequency distribution. Inspection of the calculations and curves indicates that this is largely due to the greater frequencies of the larger deviations found in the actual

data. The squaring of these deviations in the process of calculating the probable error causes them to be of appreciable influence when associated with the higher frequency values. Either, then, the normal law of error does not strictly apply to our conditions, or the relatively large frequencies of the variations at the tails of the curve are due to environmental influences which may be considered as beyond the effect of chance. Knowing the effect of straight ditches, outside plots and differences in soil fertility on plot yields, it seems logical to conclude that the discrepancy is due largely to unusual environmental influences. If we accept this assumption, then the elaboration of a system of plot omissions is in order.

The suggestion that all plots be omitted, which, from the normal curve of error, can be expected to occur only once in a thousand trials, or that this limit be three times the value of the standard deviation, seems too inclusive. Applying these suggestions to the normal curve of error for the cane variations about mean differences, from contiguous plot comparisons (Fig. 6), we find that the limits become ± 19.9 and ± 18.2 tons of cane respectively. Practically, this virtually includes the entire range of the normal curve of error and when applied to a test dealing with a small number of plots, is of rather doubtful value.

From the normal curve of error, the range within which n — 1 plots can be expected to occur or the area under the curve represented by $\frac{n-1}{n}$ of the total, is quite definite. However, the nth plot may be expected to occur at any point between the limits of the area $\frac{n-1}{n}$ to, theoretically, infinity or under practical conditions let us say, from Fig. 6, ± 20 tons of cane. Obviously, our point of omission must lie somewhere within this lower range and that point is suggested which, in view of the discrepancies noted above between the actual frequency data and the fitted curves, we may term the probable error of the nth plot. In other words, we may expect from the fitted normal curve of error, that one plot will lie below this specified point once in every two experiments of n plots each. This point is represented by the area $\frac{2n-1}{2n}$ under the normal curve of error. Applying this, for example, to experiments dealing with ten contiguous plot comparisons, we find, from the values of the probability integral and Fig. 6, that the point of omission is ± 11.9 tons of cane.

During the compilation of the data summarized in Tables I and II, it was noted that the extreme limits of variation were progressively extended, in so far as continuous data were concerned, as the number of plots considered became greater and greater. This is of course to be expected but is some indication that conditions represented by normal curves of error which refer to and are derived from very large numbers of plots or plot comparisons, cannot be indiscriminately applied to single tests involving a small number of individuals.

In Table III, the suggested points of omission for the ten normal curves of error presented in this report, have been calculated for tests involving 2 to 30 individuals. In the application of this table, omissions are to be made progressively and one at a time, omitting the greatest variant at each step until all cases are to be found within the limits of Table III. After each omission, the limits of omission change in accordance with the smaller number of individuals remaining.

We have applied the omissions of Table III to our experimental data at hand dealing with contiguous plot comparisons in cane only and this is summarized in Table IV. The number of plots per test (n) after omissions has been carried only up to the point where at least ten tests are available. It is of note that the average number of omissions per test for each group fluctuates about one and averages over the whole almost exactly one. This is not at all excessive and is probably at least approximated in actual work where the omissions are made as a matter of individual judgment.

The "mean standard deviation" of Table IV is the arithmetical average of the standard deviations of the individual tests, while the "standard deviation of distribution" is that derived by building up individual plot variations so as to form the frequency curve for the conditions given. The "standard deviation of the standard deviation" was obtained by the usual procedure dealing with positive values of the standard deviation only. These data are quite erratic and of doubtful value for purposes of generalization.

An empirical formula fitted to the values of the mean standard deviation gives:

$$\text{Mean } \delta = \delta N \left(\frac{n-1}{n}\right)^{\sqrt{2}} = 6.06 \left(\frac{n-1}{n}\right)^{1.41}$$

where δN is the standard deviation of the normal curve of error concerned.
n is the number of plots per test after omissions.

When the number of plots per test becomes infinite, the average standard deviation must of course be equal to that of the normal curve of error.

From this empirical formula, the mean standard deviation to be expected from contiguous plot comparisons has been calculated (Table V) for numbers of comparisons per test, after omissions, ranging from 2 to 30. Applying Student's method with odds of 30 : 1 to these data, gives the limits of significance according to the number of comparisons per test for the average experiment (Table VI). The data of Table VI can be considered only as a guide to the laying out of experiments. It is particularly interesting to note that after the number of comparisons per test exceeds about fourteen, appreciably greater accuracy can be obtained only at the expense of many more plots scarcely commensurate with the increased accuracy to be obtained.

In the interpretation of experimental data, it is proposed to use Student's method after the omissions have been made as indicated. Tests of two plot comparisons only, are of doubtful value under any conditions since the standard deviation must be directly equal to the variation. In other words, there is no opportunity for the variation to approximate the distribution of the normal curve of error. In the data at hand on cane comparisons, of the twenty-four tests of two comparisons each, nine are found below a standard deviation of one and four below 0.5.

It must be remembered that Table VI refers to average conditions. Experiment locations can be expected to occur both of smaller and of greater variation, the smaller variation locations affording appreciably higher accuracy than indicated in Table VI. It is then obviously possible through the continued harvests of experiments to locate areas suitable to a relatively high degree of accuracy. Such areas

will then be devoted to problems in which a small probable error is essential; others to such problems as may be determined by greater limits of error; and still others which are not suitable for experimental purposes at all. The determination of the location-variation may be obtained by the use of blank tests, though from a practical plantation standpoint, it would appear most suitable to carry a definite test on the area in question. The variation can then be determined either from the consideration of the checks only or from the variation of the differences of contiguous plot comparisons about the mean differences. Such a selection of areas has been followed in the past and apparently has shown good results, though not attempted in a systematic way.

The results of all experiments are reported individually on the following form:

EWA PLANTATION CO.

KIND OF EXPERIMENT.....EXPERIMENT NO.....
Field..... Crop..... Plant or Ratoon.....
Crop Began..... Crop Harvested.....
Cane Age..... Area.....

SUMMARY OF HARVESTING RESULTS

Treatment	YIELD PER ACRE: Arithmetical Average				
	Cane.	Q.R.	Sugar.	Brix.	Purity.
.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....
Gain or Loss for.....	.....	.....	.....	.....	.....
Per Cent Gain or Loss for.....	.....	.....	.....	.....	.....

PLOT TO PLOT COMPARISON

	Total	For	Same	For	Odds	Diff. Student's Method
Cane	.....	.....	.....	.....	.....	.....
Quality Ratio	.....	.....	.....	.....	.....	.....
Sugar	.....	.....	.....	.....	.....	.....
Brix	.....	.....	.....	.....	.....	.....
Purity	.....	.....	.....	.....	.....	.....

Details of Treatments:
Interpretation:

Under the heading "Yield Per Acre", the arithmetical treatment-averages are entered after omitting according to the data of Table III under "Per Cent of Means." Percentages are then expressed on the basis of the check treatment or, in case of doubt, on that treatment most closely approximating the plantation practice of the current crop.

Under "Plot to Plot Comparison," entries under the column "same" are determined by the probable error of the mean difference as determined from the fitted normal curves of error of Figs. 6 to 10, inclusive, by the formula $\text{P.E.m} = \frac{\text{P.E.s}}{\sqrt{n}}$.

Plot comparisons greater or less than the probable error of the mean are entered in

the other two columns according to whether the differences indicate the treatment or the check as the more productive.

Summary

1. Normal curves of error have been fitted to the data obtained from about 5000 harvested experimental plots of watercourse size. Variation about the means in per cent of the mean and variation of contiguous plot comparison differences about the mean difference, have been considered under cane, quality ratio, sugar, Brix and purity.

2. A table of omissions has been calculated based on the normal curves of error and the area $\frac{2n-1}{2n}$ under the curves, where n is the number of plots.

3. This table of omissions has been applied to the data at hand and indicates an average omission of one plot per test. This is not excessive.

4. From the mean standard deviations of tests involving two to fifteen individuals, an empirical formula has been developed in relation to the normal curve of error, giving the mean standard deviation to be expected from tests of n plots.

5. From the calculated mean standard deviations and Student's method, using odds of 30 : 1, mean limits of significance have been calculated.

6. A form and procedure for the summary of experiments has been outlined.

TABLE I

Normal Curves of Error From Harvested Experiment Plots—Variation About Means in Per Cent of Means

Class Value	Actual Data—Per Cent Frequency					Calculated from Curves—Per Cent Frequency				
	Cane	Q.R.	Sugar	Brix	Purity	Cane	Q.R.	Sugar	Brix	Purity
67.5			0.04							
68.5			0.11							
69.5			0.02							
70.5			0.02							
71.5	0.09		0.02							
72.5	0.09		0.13							
73.5	0.11		0.22							
74.5	0.09		0.09							
75.5	0.07		0.11							
76.5	0.15		0.13							
77.5	0.15		0.16							
78.5	0.20		0.27							
79.5	0.44		0.18			0.09		0.07		
80.5	0.36		0.16			0.13		0.10		
81.5	0.38	0.02	0.27			0.19		0.15		
82.5	0.49	0.04	0.38			0.27		0.22		
83.5	0.65	0.05	0.47			0.38		0.32		
84.5	0.71	0.09	0.52			0.52		0.45		
85.5	0.85	0.11	0.70			0.70		0.62		
86.5	0.98	0.15	0.58			0.93		0.84		
87.5	1.25	0.18	1.14	0.05		1.20	0.15	1.10		
88.5	1.38	0.40	1.07	0.07		1.52	0.27	1.42		
89.5	1.49	0.44	1.41	0.11		1.89	0.49	1.80		
90.5	1.87	1.03	1.63	0.22	0.02	2.30	0.83	2.23	0.05	
91.5	2.69	1.62	1.88	0.34	0.07	2.75	1.34	2.70	0.15	
92.5	2.87	2.16	3.20	0.78	0.05	3.22	2.05	3.20	0.40	
93.5	3.72	2.49	3.27	1.12	0.11	3.70	2.98	3.71	0.97	
94.5	4.17	3.90	3.94	2.18	0.18	4.16	4.11	4.20	2.09	

TABLE I (Continued)

Normal Curves of Error From Harvested Experiment Plots—Variation About Means in Per Cent of Means

Class Value	Actual Data—Per Cent Frequency					Calculated from Curves—Per Cent Frequency				
	Cane	Q.R.	Sugar	Brix	Purity	Cane	Q.R.	Sugar	Brix	Purity
95.5	3.90	5.43	4.55	3.75	0.71	4.59	5.37	4.69	3.93	0.04
96.5	5.14	6.79	5.19	5.22	1.23	4.97	6.65	5.11	6.54	0.59
97.5	5.48	8.58	5.95	8.38	4.50	5.27	7.80	5.45	9.56	1.54
98.5	6.02	8.89	6.13	11.79	12.88	5.49	8.68	5.69	12.32	15.46
99.5	5.35	9.84	6.09	15.09	27.92	5.60	9.16	5.81	13.99	29.75
100.5	5.68	9.75	6.29	14.82	32.02	5.60	9.16	5.81	13.99	29.75
101.5	5.53	8.10	5.93	13.67	14.33	5.49	8.68	5.69	12.32	15.46
102.5	5.08	6.73	6.13	8.85	4.08	5.27	7.80	5.45	9.56	1.54
103.5	4.36	5.61	5.04	5.86	1.51	4.97	6.65	5.11	6.54	0.59
104.5	4.32	4.14	4.25	3.57	0.27	4.59	5.37	4.69	3.93	0.04
105.5	3.52	3.19	3.79	1.83	0.11	4.16	4.11	4.20	2.09	
106.5	3.01	2.58	3.05	1.03		3.70	2.98	3.71	0.97	
107.5	2.74	2.20	2.78	0.63		3.22	2.05	3.20	0.40	
108.5	2.16	1.45	2.20	0.31		2.75	1.34	2.70	0.15	
109.5	1.91	1.18	1.83	0.13		2.30	0.83	2.23	0.05	
110.5	1.81	0.76	1.34	0.09		1.89	0.49	1.80		
111.5	1.52	0.60	1.52	0.09		1.52	0.27	1.42		
112.5	1.13	0.33	1.08			1.20	0.15	1.10		
113.5	0.80	0.29	0.72			0.93		0.84		
114.5	0.69	0.15	0.60			0.70		0.62		
115.5	0.60	0.20	0.51			0.52		0.45		
116.5	0.56	0.13	0.36			0.38		0.32		
117.5	0.45	0.13	0.45			0.27		0.22		
118.5	0.64	0.18	0.38			0.19		0.15		

TABLE I (Continued)

Normal Curves of Error From Harvested Experiment Plots—Variation About Means in Per Cent of Means

Class Value	Actual Data—Per Cent Frequency					Calculated from Curves—Per Cent Frequency				
	Cane	Q.R.	Sugar	Brix	Purity	Cane	Q.R.	Sugar	Brix	Purity
119.5	0.40	0.09	0.23			0.13		0.10		
120.5	0.42	0.02	0.34			0.09		0.07		
121.5	0.25		0.16							
122.5	0.16		0.16							
123.5	0.18		0.04							
124.5	0.20		0.13							
125.5	0.09		0.13							
126.5	0.16		0.13							
127.5	0.02		0.07							
128.5	0.11		0.11							
129.5	0.07		0.07							
130.5	0.09		0.07							
131.5	0.04		0.07							
132.5	0.04		0.04							
Total Number	5511	5509	5534	5514	5512					
St. Deviation	±8.42	±4.83	±7.94	±2.96	±1.44					
P.E.s	±5.68	±3.26	±5.36	±2.00	±0.97					

TABLE II

Normal Curves of Error for Cane
Variation in Tons Cane Per Acre About Mean Differences From Contiguous Plot Comparisons

Per Cent Frequency

Class Value	Actual Data	Calculated
—22.5	0.02	
—21.5	0.02	
—20.5	0.02	
—19.5	0.02	
—18.5	0.36	0.06
—17.5	0.29	0.10
—16.5	0.44	0.16
—15.5	0.74	0.25
—14.5	0.74	0.38
—13.5	0.93	0.55
—12.5	0.97	0.78
—11.5	1.24	1.09
—10.5	1.58	1.47
— 9.5	1.75	1.93
— 8.5	2.13	2.46
— 7.5	3.16	3.06
— 6.5	3.31	3.71
— 5.5	4.05	4.36
— 4.5	4.11	5.00
— 3.5	5.08	5.57
— 2.5	6.34	6.05
— 1.5	5.84	6.38
— 0.5	6.01	6.57
0.5	6.41	6.57
1.5	6.19	6.38
2.5	6.13	6.05
3.5	5.60	5.57
4.5	4.72	5.00
5.5	4.40	4.36
6.5	3.43	3.71
7.5	3.10	3.06
8.5	2.04	2.46
9.5	1.79	1.93
10.5	1.75	1.47
11.5	1.24	1.09
12.5	0.88	0.78
13.5	1.10	0.55
14.5	0.63	0.38
15.5	0.42	0.25
16.5	0.40	0.16
17.5	0.23	0.10
18.5	0.34	0.06
19.5	0.04	
Total Number	4746	
St. Deviation	±6.73	
P.E. s	±4.54	

TABLE II (Continued)

Normal Curves of Error. Variation in Original Units About Mean Differences From Contiguous Plot Comparisons

Class Value	Actual Data—Per Cent Frequency				Calculated From Curves—Per Cent Frequency			
	Q.R.	Sugar	Brix	Purity	Q.R.	Sugar	Brix	Purity
—3.55		0.04						
—3.45		0.06						
—3.35		0.08		0.04				
—3.25		0.10		0.06				
—3.15		0.04		0.08				
—3.05		0.14		0.10				
—2.95		0.06		0.17				
—2.85		0.06		0.17				
—2.75		0.08		0.29				
—2.65		0.10		0.17				0.09
—2.55		0.12		0.17				0.12
—2.45		0.04		0.33				0.16
—2.35		0.21		0.23				0.21
—2.25		0.23		0.46		0.07		0.27
—2.15		0.23		0.44		0.11		0.34
—2.05		0.25		0.59		0.15		0.43
—1.95		0.57	0.04	0.54		0.21		0.53
—1.85		0.53	0.14	0.69		0.29		0.65
—1.75	0.04	0.49	0.02	0.82		0.39		0.79
—1.65	0.04	0.57	0.23	1.19		0.52		0.95
—1.55	0.10	0.66	0.08	1.30		0.69		1.13
—1.45	0.13	0.96	0.23	1.15		0.88		1.33
—1.35	0.23	0.76	0.29	1.59		1.12	0.08	1.55
—1.25	0.19	1.17	0.33	1.44		1.39	0.15	1.78
—1.15	0.25	1.58	0.45	1.90	0.04	1.70	0.28	2.03
—1.05	0.40	1.93	0.66	1.69	0.11	2.05	0.50	2.29
—0.95	0.58	2.01	0.77	1.92	0.25	2.42	0.85	2.55
—0.85	0.71	2.50	1.70	2.74	0.53	2.82	1.36	2.81
—0.75	1.42	2.87	1.90	3.03	1.06	3.23	2.08	3.06
—0.65	1.84	3.47	2.73	3.26	1.92	3.63	3.01	3.30
—0.55	2.55	3.90	3.85	3.58	3.21	4.01	4.13	3.52
—0.45	4.26	4.33	5.28	3.55	4.91	4.37	5.37	3.72
—0.35	5.87	4.90	6.71	3.64	6.92	4.67	6.63	3.88
—0.25	9.17	4.70	7.60	4.31	8.93	4.91	7.77	4.01
—0.15	10.98	5.07	9.15	4.06	10.59	5.08	8.64	4.10
—0.05	10.57	4.74	8.22	3.97	11.53	5.17	9.10	4.15
0.05	12.59	4.97	9.03	4.25	11.53	5.17	9.10	4.15
0.15	11.00	5.48	8.80	4.25	10.59	5.08	8.64	4.10
0.25	8.12	4.82	7.24	4.27	8.93	4.91	7.77	4.01
0.35	6.06	4.82	6.06	3.22	6.92	4.67	6.63	3.88
0.45	3.82	4.60	4.72	4.12	4.91	4.37	5.37	3.72
0.55	3.13	3.47	4.02	3.55	3.21	4.01	4.13	3.52
0.65	2.00	3.28	2.84	3.03	1.92	3.63	3.01	3.30
0.75	1.25	3.32	1.53	2.59	1.06	3.23	2.08	3.06
0.85	0.88	2.28	1.41	2.53	0.53	2.82	1.36	2.81
0.95	0.58	2.32	1.18	2.66	0.25	2.42	0.85	2.55
1.05	0.33	1.66	0.79	2 11	0.11	2.05	0.50	2 29
1.15	0.31	1.58	0.52	1.86	0.04	1.70	0.28	2.03
1.25	0.21	1.50	0.43	1.46		1.39	0.15	1.78
1.35	0.04	1.13	0.35	1.57		1.12	0.08	1.55

TABLE II (Continued)

Normal Curves of Error. Variation in Original Units About Mean Differences From Contiguous Plot Comparisons

Class Value	Actual Data—Per Cent Frequency				Calculated From Curves—Per Cent Frequency			
	Q.R.	Sugar	Brix	Purity	Q.R.	Sugar	Brix	Purity
1.45	0.06	0.86	0.21	1.46		0.88		1.33
1.55	0.17	0.59	0.21	1.42		0.69		1.13
1.65	0.02	0.68	0.10	0.84		0.52		0.95
1.75	0.04	0.41	0.08	0.90		0.39		0.79
1.85	0.04	0.49	0.06	0.63		0.29		0.65
1.95		0.33	0.04	0.54		0.21		0.53
2.05		0.25		0.52		0.15		0.43
2.15		0.33		0.40		0.11		0.34
2.25		0.14		0.27		0.07		0.27
2.35		0.14		0.36				0.21
2.45		0.14		0.25				0.16
2.55		0.14		0.33				0.12
2.65		0.08		0.31				0.09
2.75		0.18		0.21				
2.85		0.04		0.06				
2.95		0.10		0.10				
3.05		0.06		0.06				
3.15		0.04		0.04				
3.25		0.06		0.06				
3.35		0.04		0.06				
3.45		0.04						
3.55		0.04						
Total Number	4789	4874	4831	4782				
St. Deviation	±0.40	±0.90	±0.50	±1.04				
P.E.s	±0.27	±0.60	±0.34	±0.70				

Suggested Omissions—Variations About Mean Differences in Original Units; and About Treatment Means in Per Cent

No.	Cane Tons	Q.R.	Sugar	Brix	Purity	n	Per Cent of Means: Cane %	Q.R.	Sugar	Brix	Purity	n
2	±6.97	±0.39	±0.89	±0.50	±1.11	2	±8.18	±4.98	±7.88	±3.23	±1.42	2
3	8.38	0.47	1.07	0.60	1.33	3	9.84	5.98	9.48	3.88	1.71	3
4	9.30	0.53	1.18	0.67	1.48	4	10.91	6.64	10.51	4.31	1.90	4
5	9.97	0.56	1.27	0.72	1.58	5	11.70	7.12	11.27	4.62	2.04	5
6	10.49	0.59	1.33	0.75	1.67	6	12.32	7.49	11.87	4.86	2.14	6
7	10.92	0.62	1.39	0.79	1.73	7	12.82	7.80	12.35	5.06	2.23	7
8	11.29	0.64	1.44	0.81	1.79	8	13.25	8.06	12.76	5.23	2.31	8
9	11.60	0.66	1.48	0.83	1.84	9	13.62	8.28	13.12	5.37	2.37	9
10	11.88	0.67	1.51	0.85	1.88	10	13.94	8.48	13.43	5.50	2.43	10
11	12.12	0.68	1.54	0.87	1.92	11	14.23	8.66	13.71	5.62	2.48	11
12	12.34	0.70	1.57	0.89	1.96	12	14.49	8.81	13.96	5.72	2.52	12
13	12.54	0.71	1.60	0.90	1.99	13	14.72	8.96	14.18	5.81	2.56	13
14	12.73	0.72	1.62	0.91	2.02	14	14.94	9.09	14.39	5.90	2.60	14
15	12.90	0.73	1.64	0.93	2.05	15	15.14	9.21	14.58	5.97	2.63	15
16	13.05	0.74	1.66	0.94	2.07	16	15.32	9.32	14.76	6.05	2.67	16
17	13.20	0.75	1.68	0.95	2.09	17	15.49	9.42	14.92	6.11	2.70	17
18	13.33	0.75	1.70	0.96	2.12	18	15.65	9.52	15.08	6.18	2.72	18
19	13.46	0.76	1.71	0.97	2.14	19	15.80	9.61	15.22	6.24	2.75	19
20	13.58	0.77	1.73	0.98	2.16	20	15.94	9.70	15.36	6.29	2.77	20
21	13.70	0.77	1.74	0.98	2.17	21	16.08	9.78	15.49	6.34	2.80	21
22	13.80	0.78	1.76	0.99	2.19	22	16.20	9.86	15.61	6.39	2.82	22
23	13.91	0.79	1.77	1.00	2.21	23	16.33	9.93	15.72	6.44	2.84	23
24	14.00	0.79	1.78	1.01	2.22	24	16.44	10.00	15.83	6.49	2.86	24
25	14.10	0.80	1.79	1.01	2.24	25	16.55	10.07	15.94	6.53	2.88	25
26	14.19	0.80	1.80	1.02	2.25	26	16.65	10.13	16.04	6.57	2.90	26
27	14.27	0.81	1.82	1.03	2.26	27	16.75	10.19	16.14	6.61	2.91	27
28	14.35	0.81	1.83	1.03	2.28	28	16.85	10.25	16.23	6.65	2.93	28
29	14.43	0.82	1.84	1.04	2.29	29	16.94	10.31	16.32	6.69	2.95	29
30	14.51	0.82	1.85	1.04	2.30	30	17.03	10.36	16.40	6.72	2.96	30

TABLE IV

Contiguous Plot Comparisons—Cane Only. Application of Table of Omissions and Data on Standard Deviations

No. of Comparisons Per Test*	Av. No. of Comparisons Omitted Per Test	No. of Tests	Mean St. Dev.	St. Dev. of Distribution	Calculated Mean St. Dev. (Formula)	St. Dev. of St. Deviation
2	1.46	24	1.95	2.50	2.28	1.56
3	0.87	39	3.98	4.41	3.42	1.91
4	1.09	57	4.26	4.48	4.04	1.39
5	1.11	75	4.21	4.46	4.42	1.46
6	0.59	69	4.28	4.44	4.69	1.22
7	0.94	62	4.63	4.77	4.88	1.18
8	1.04	50	5.09	5.22	5.02	1.18
9	1.30	40	4.93	5.04	5.12	1.07
10	0.96	24	5.44	5.52	5.22	0.96
11	1.61	18	5.48	5.59	5.30	1.10
12	0.58	12	5.11	5.19	5.36	0.89
13	1.33	18	5.41	5.57	5.41	1.32
14	1.15	26	5.50	5.64	5.46	1.22
15	0.80	10	5.69	5.77	5.50	0.91
Total & Averages	1.01	524				

* After omissions.

Formula

$$\text{Mean St. Dev.} = 6.06 \left(\frac{n-1}{n} \right)^{1.41}$$

TABLE V

Mean Standard Deviation From Formula

No. of Comparisons Per Test	Cane	Q.R.	Sugar	Brix	Purity
2	2.28	0.129	0.290	0.164	0.362
3	3.42	0.193	0.435	0.246	0.543
4	4.04	0.228	0.514	0.291	0.641
5	4.42	0.250	0.563	0.318	0.702
6	4.69	0.264	0.596	0.337	0.744
7	4.88	0.275	0.620	0.351	0.774
8	5.02	0.283	0.639	0.361	0.797
9	5.12	0.289	0.651	0.368	0.813
10	5.22	0.295	0.665	0.376	0.829
11	5.30	0.299	0.674	0.381	0.841
12	5.36	0.303	0.682	0.386	0.851
13	5.41	0.306	0.689	0.389	0.859
14	5.46	0.308	0.695	0.393	0.867
15	5.50	0.310	0.700	0.396	0.873
16	5.53	0.312	0.704	0.398	0.878
17	5.56	0.314	0.708	0.400	0.883
18	5.59	0.316	0.711	0.402	0.888
19	5.62	0.317	0.714	0.404	0.891
20	5.64	0.318	0.717	0.406	0.895
21	5.66	0.319	0.720	0.407	0.898
22	5.68	0.320	0.722	0.408	0.901
23	5.69	0.321	0.724	0.409	0.904
24	5.71	0.322	0.726	0.411	0.906
25	5.72	0.323	0.728	0.412	0.908
26	5.73	0.324	0.730	0.413	0.910
27	5.75	0.324	0.731	0.413	0.912
28	5.76	0.325	0.732	0.414	0.914
29	5.77	0.325	0.734	0.415	0.916
30	5.78	0.326	0.735	0.416	0.917

TABLE VI

Limits of Significance by Student's Method (Odds 30 : 1)
Using Mean Standard Deviation

No. of Comparisons Per Test	Cane	Q.R.	Sugar	Brix	Purity
2	22.4	1.27	2.85	1.61	3.56
3	9.0	0.51	1.15	0.65	1.44
4	6.7	0.38	0.85	0.48	1.06
5	5.6	0.32	0.71	0.40	0.89
6	5.0	0.28	0.63	0.36	0.79
7	4.5	0.25	0.57	0.32	0.72
8	4.2	0.23	0.53	0.30	0.66
9	3.9	0.22	0.49	0.28	0.62
10	3.7	0.21	0.47	0.26	0.58
11	3.5	0.20	0.44	0.25	0.56
12	3.3	0.19	0.42	0.24	0.53
13	3.2	0.18	0.41	0.23	0.51
14	3.1	0.17	0.39	0.22	0.49
15	3.0	0.17	0.38	0.21	0.47
16	2.9	0.16	0.36	0.21	0.45
17	2.8	0.16	0.35	0.20	0.44
18	2.7	0.15	0.34	0.19	0.43
19	2.6	0.15	0.33	0.19	0.42
20	2.6	0.15	0.33	0.19	0.41
21	2.5	0.14	0.32	0.18	0.40
22	2.4	0.14	0.31	0.18	0.39
23	2.4	0.13	0.30	0.17	0.38
24	2.3	0.13	0.29	0.17	0.37
25	2.3	0.13	0.29	0.16	0.36
26	2.2	0.13	0.28	0.16	0.35
27	2.2	0.12	0.28	0.16	0.34
28	2.1	0.12	0.27	0.16	0.34
29	2.1	0.12	0.27	0.15	0.34
30	2.1	0.12	0.27	0.15	0.33

TABLE VII

Limits (Inclusive) for Plot to Plot Comparison Summaries Under "Same"

Number	Cane	Q.R.	Sugar	Brix	Purity
2	±2.89	±0.16	±0.37	±0.21	±0.46
3	2.36	0.13	0.30	0.17	0.37
4	2.04	0.12	0.26	0.15	0.32
5	1.83	0.10	0.23	0.13	0.29
6	1.67	0.09	0.21	0.12	0.26
7	1.54	0.09	0.20	0.11	0.25
8	1.44	0.08	0.18	0.10	0.23
9	1.36	0.08	0.17	0.10	0.22
10	1.29	0.07	0.16	0.09	0.21
11	1.23	0.07	0.16	0.09	0.20
12	1.18	0.07	0.15	0.08	0.19
13	1.13	0.06	0.14	0.08	0.18
14	1.09	0.06	0.14	0.08	0.17
15	1.06	0.06	0.13	0.08	0.17
16	1.02	0.06	0.13	0.07	0.16
17	0.99	0.06	0.13	0.07	0.16
18	0.96	0.05	0.12	0.07	0.15
19	0.94	0.05	0.12	0.07	0.15
20	0.91	0.05	0.12	0.07	0.15
21	0.89	0.05	0.11	0.06	0.14
22	0.87	0.05	0.11	0.06	0.14
23	0.85	0.05	0.11	0.06	0.14
24	0.83	0.05	0.11	0.06	0.13
25	0.82	0.05	0.10	0.06	0.13
26	0.80	0.05	0.10	0.06	0.13
27	0.79	0.04	0.10	0.06	0.12
28	0.77	0.04	0.10	0.06	0.12
29	0.76	0.04	0.10	0.05	0.12
30	0.75	0.04	0.09	0.05	0.12

$$\text{Inclusive Limits} = \text{P.E. m} = \frac{\text{P.E. s}}{\sqrt{n}}$$

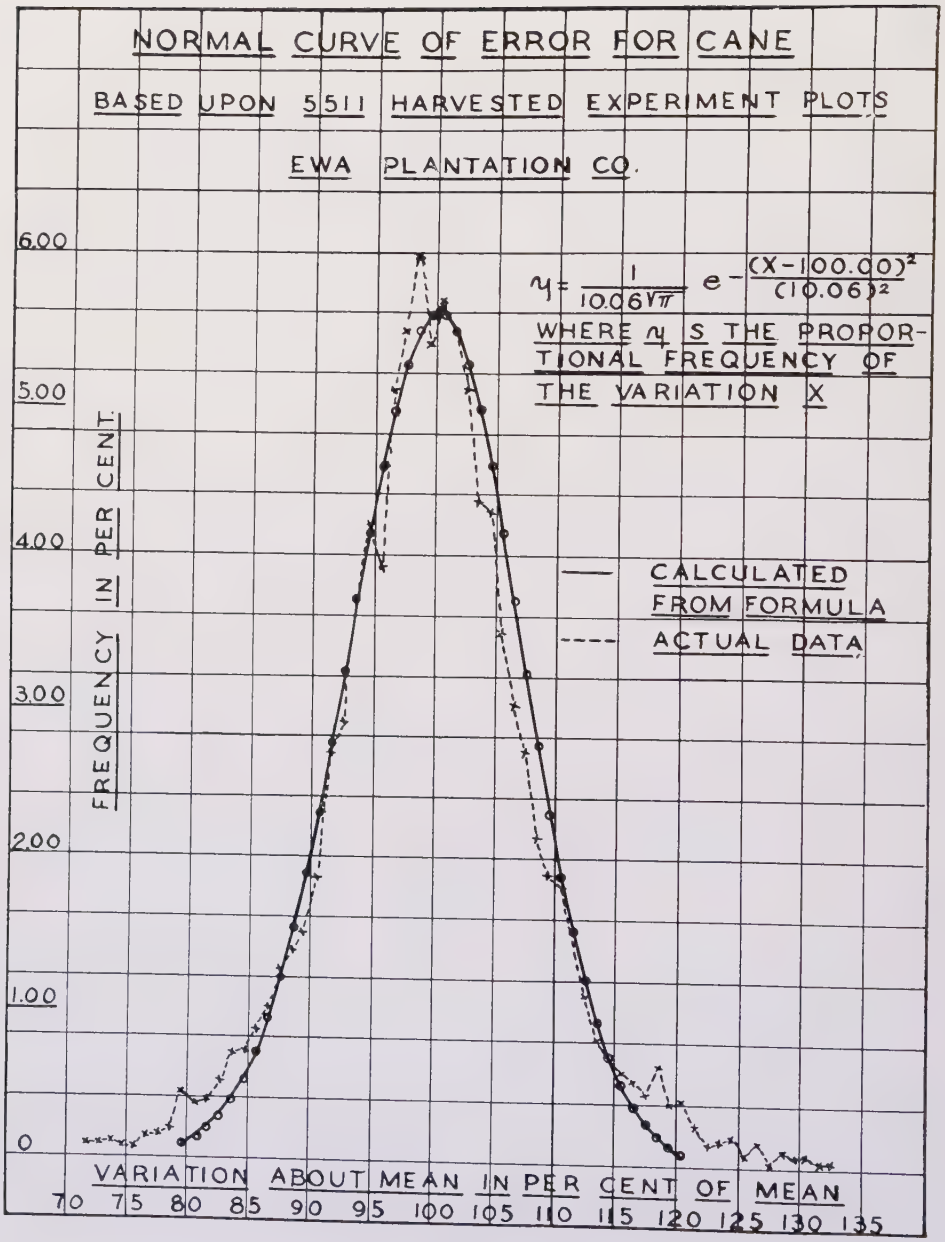

NORMAL CURVE OF ERROR FOR CANE
BASED UPON 5511 HARVESTED EXPERIMENT PLOTS
EWA PLANTATION CO.
$y = \frac{1}{10.06\sqrt{\pi}} e^{-\frac{(X-100.00)^2}{(10.06)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT.
6.00
5.00
4.00
3.00
2.00
1.00
0
VARIATION ABOUT MEAN IN PER CENT OF MEAN
70 75 80 85 90 95 100 105 110 115 120 125 130 135

Fig. 1

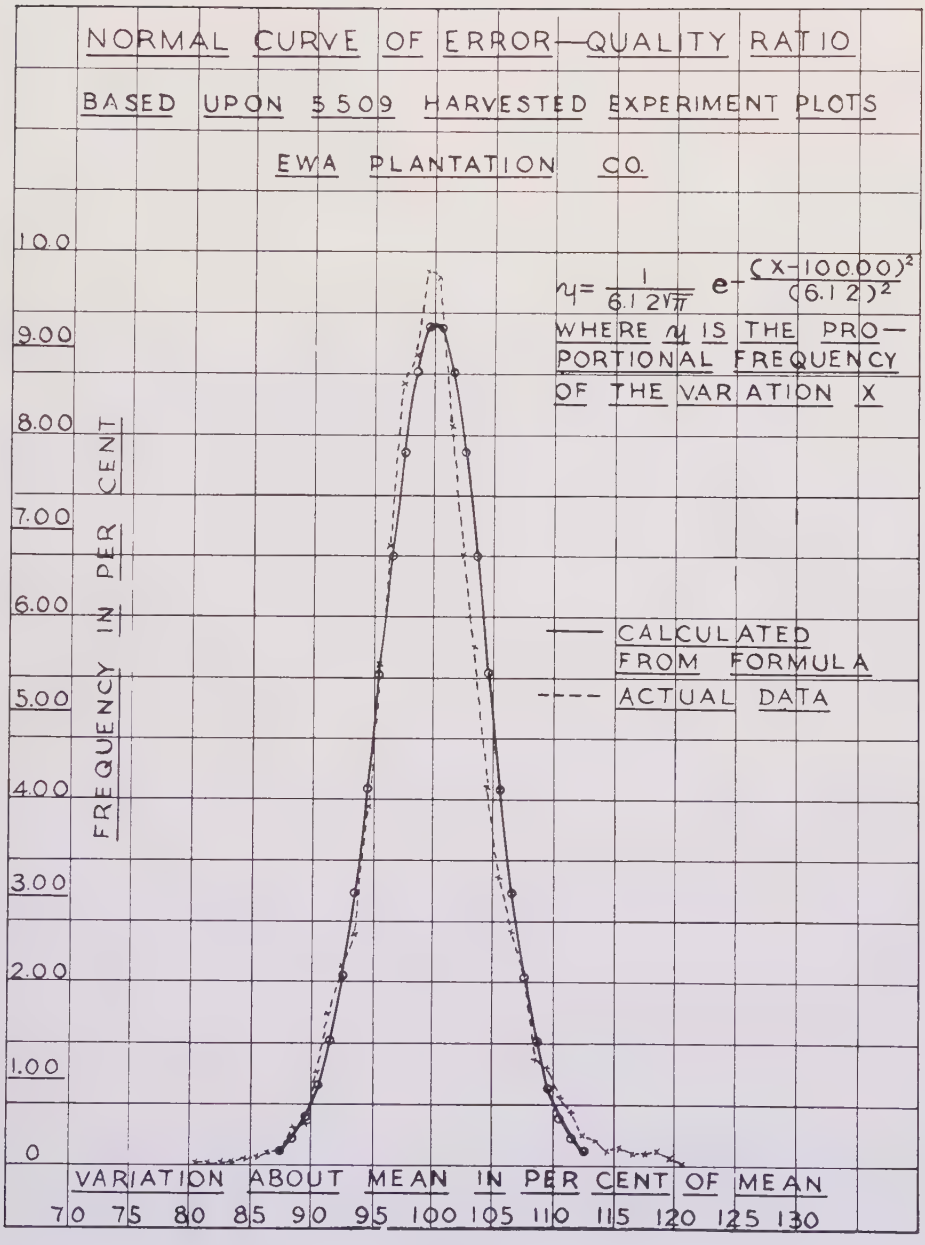

NORMAL CURVE OF ERROR—QUALITY RATIO
BASED UPON 5509 HARVESTED EXPERIMENT PLOTS
EWA PLANTATION CO.
$y = \frac{1}{6.12\sqrt{\pi}} e^{-\frac{(X-100.00)^2}{(6.12)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
VARIATION ABOUT MEAN IN PER CENT OF MEAN
70 75 80 85 90 95 100 105 110 115 120 125 130

Fig. 2

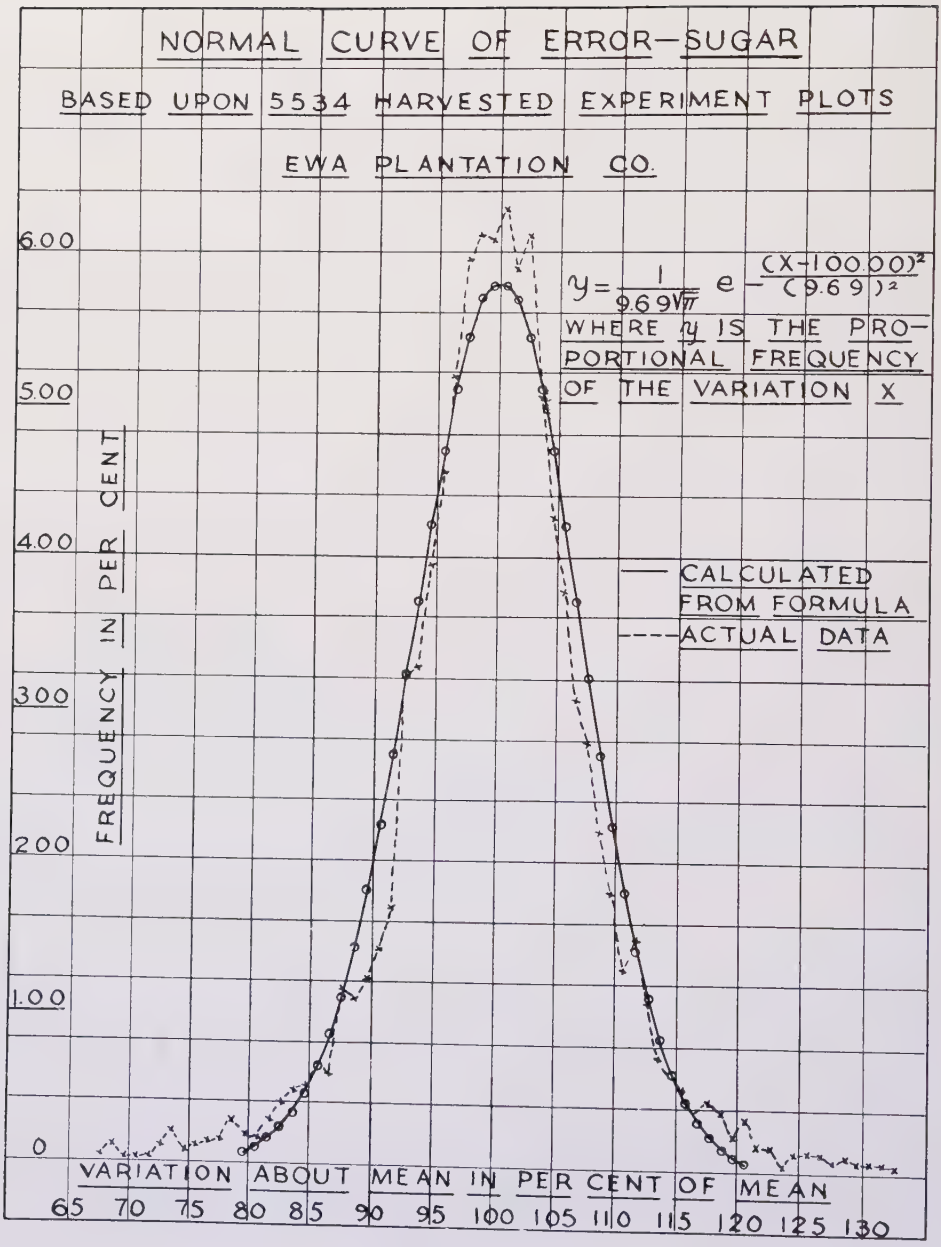

NORMAL CURVE OF ERROR—SUGAR
BASED UPON 5534 HARVESTED EXPERIMENT PLOTS
EWA PLANTATION CO.
$y = \frac{1}{9.69\sqrt{\pi}} e^{-\frac{(X-100.00)^2}{(9.69)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
6.00
5.00
4.00
3.00
2.00
1.00
0
VARIATION ABOUT MEAN IN PER CENT OF MEAN
65 70 75 80 85 90 95 100 105 110 115 120 125 130

Fig. 3

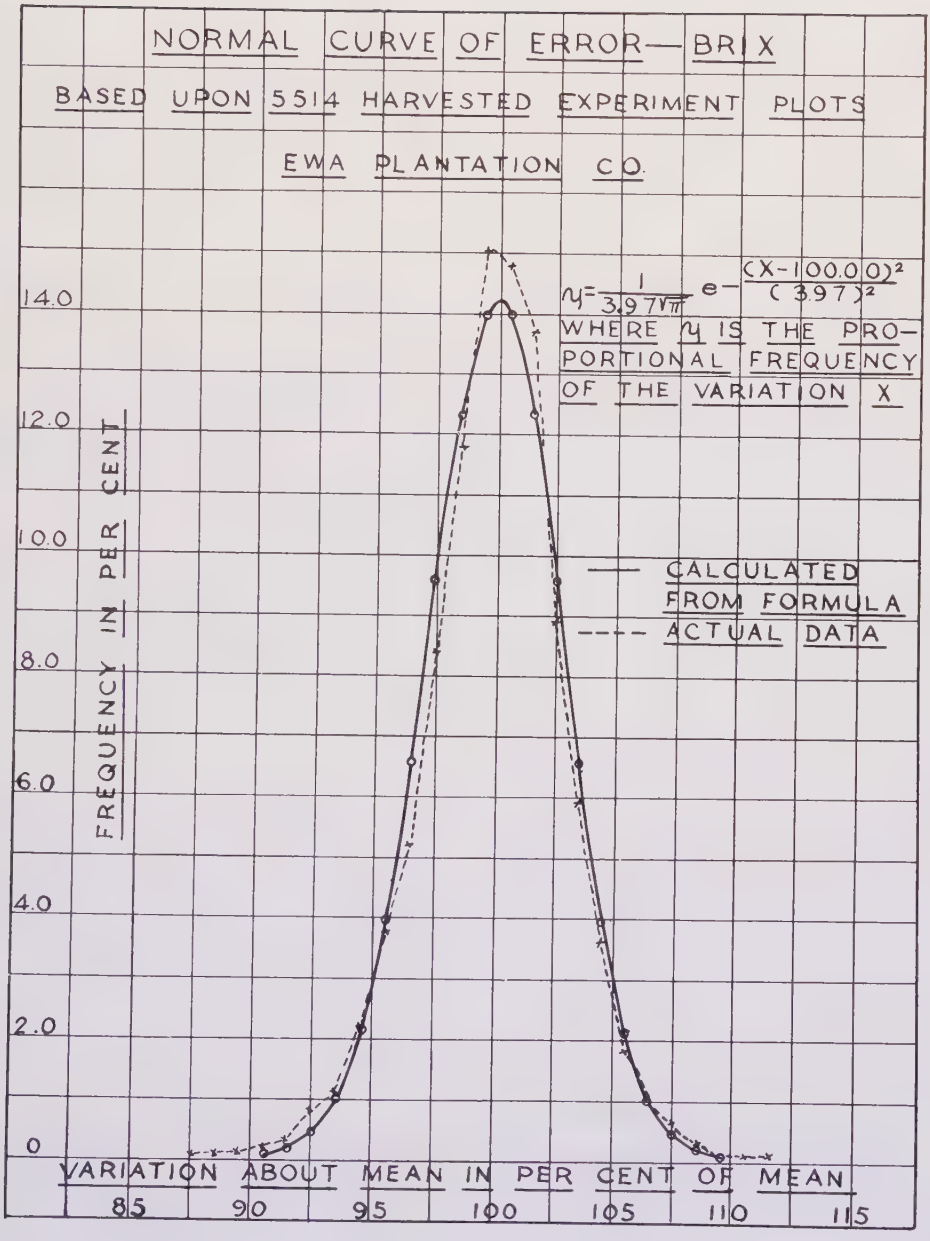

NORMAL CURVE OF ERROR—BRIX
BASED UPON 5514 HARVESTED EXPERIMENT PLOTS
EWA PLANTATION CO.
$y = \frac{1}{3.97\sqrt{\pi}} e^{-\frac{(X-100.00)^2}{(3.97)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0
VARIATION ABOUT MEAN IN PER CENT OF MEAN
85
90
95
100
105
110
115

Fig. 4

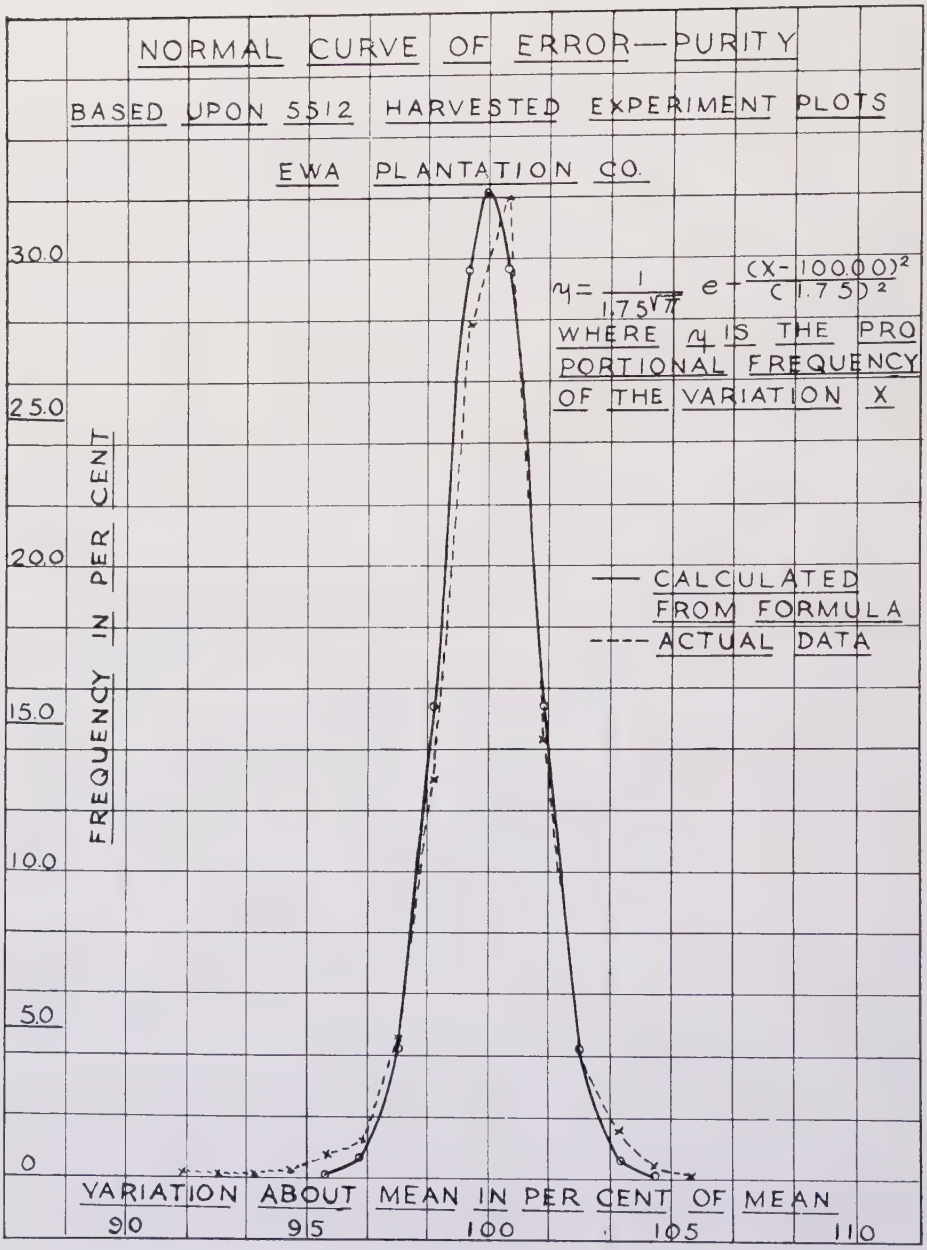

NORMAL CURVE OF ERROR—PURITY
BASED UPON 5512 HARVESTED EXPERIMENT PLOTS
EWA PLANTATION CO.
$y = \frac{1}{1.75\sqrt{\pi}} e^{-\frac{(X-100.00)^2}{(1.75)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
30.0
25.0
20.0
15.0
10.0
5.0
0
VARIATION ABOUT MEAN IN PER CENT OF MEAN
90
95
100
105
110

Fig. 5

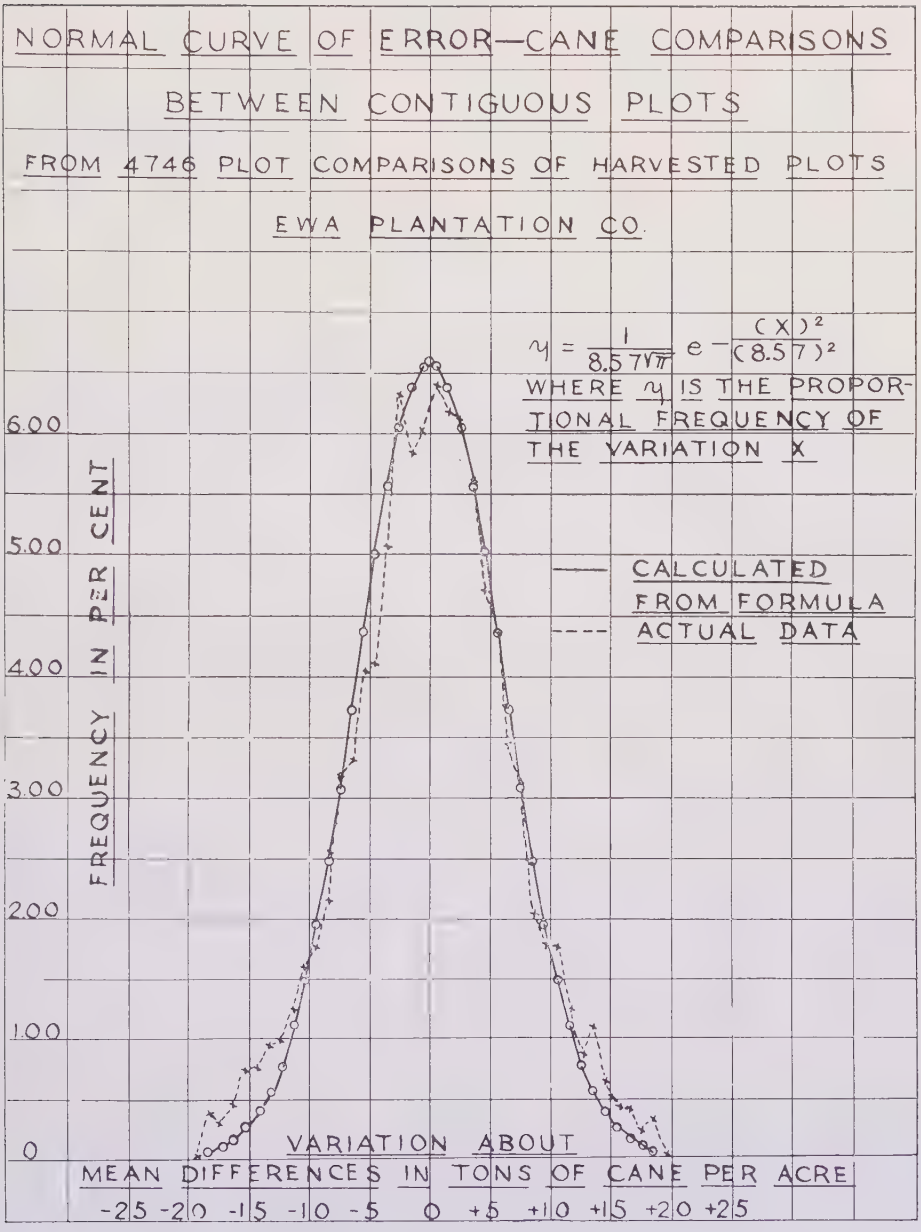

NORMAL CURVE OF ERROR—CANE COMPARISONS
BETWEEN CONTIGUOUS PLOTS
FROM 4746 PLOT COMPARISONS OF HARVESTED PLOTS
EWA PLANTATION CO.
$y = \frac{1}{8.57\sqrt{\pi}} e^{-\frac{(X)^2}{(8.57)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
6.00
5.00
4.00
3.00
2.00
1.00
0
VARIATION ABOUT
MEAN DIFFERENCES IN TONS OF CANE PER ACRE
-25 -20 -15 -10 -5 0 +5 +10 +15 +20 +25

Fig. 6

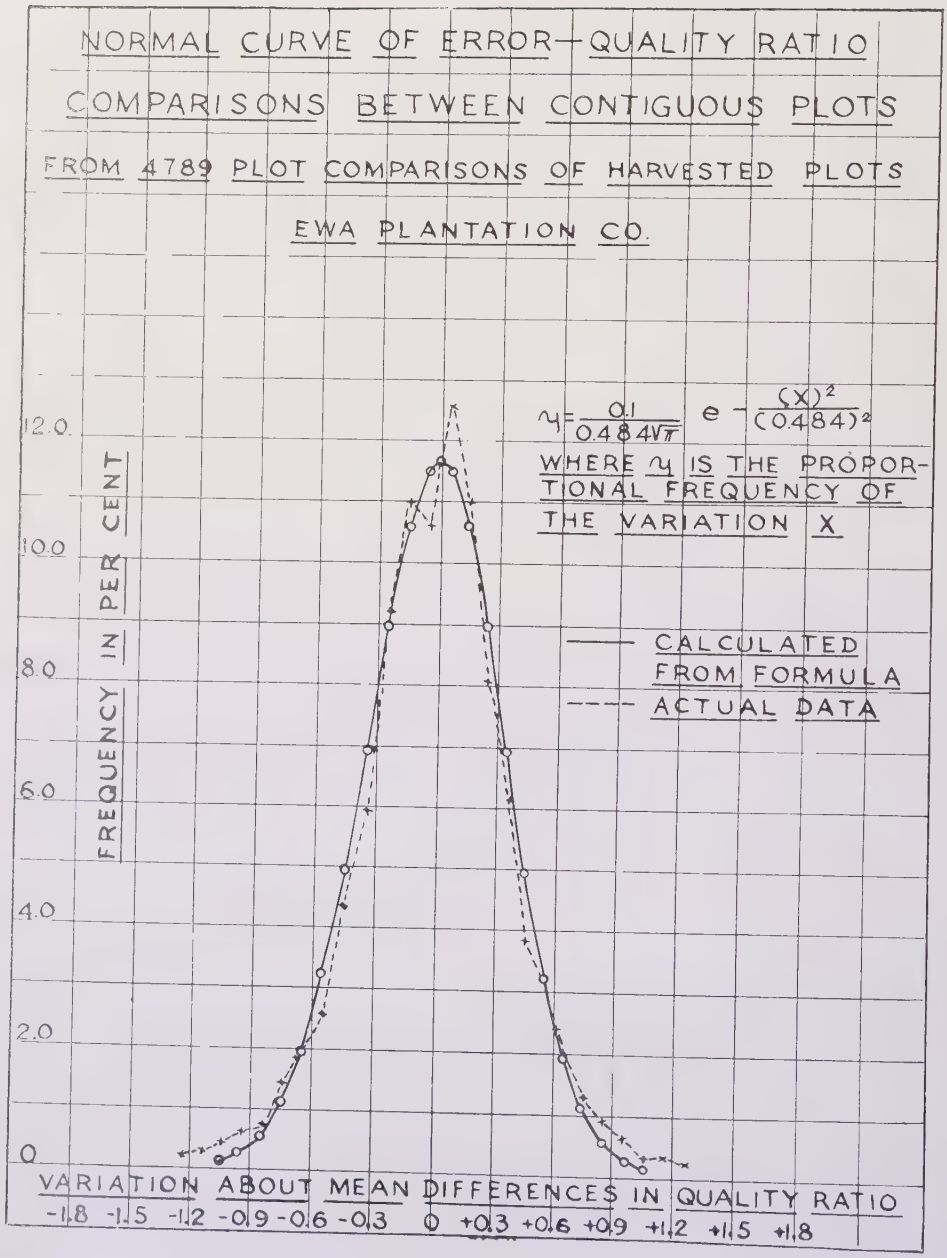

NORMAL CURVE OF ERROR—QUALITY RATIO
COMPARISONS BETWEEN CONTIGUOUS PLOTS
FROM 4789 PLOT COMPARISONS OF HARVESTED PLOTS
EWA PLANTATION CO.
$y = \frac{0.1}{0.484\sqrt{\pi}} e^{-\frac{(x)^2}{(0.484)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
12.0
10.0
8.0
6.0
4.0
2.0
0
VARIATION ABOUT MEAN DIFFERENCES IN QUALITY RATIO
-1.8 -1.5 -1.2 -0.9 -0.6 -0.3 0 +0.3 +0.6 +0.9 +1.2 +1.5 +1.8

Fig. 7

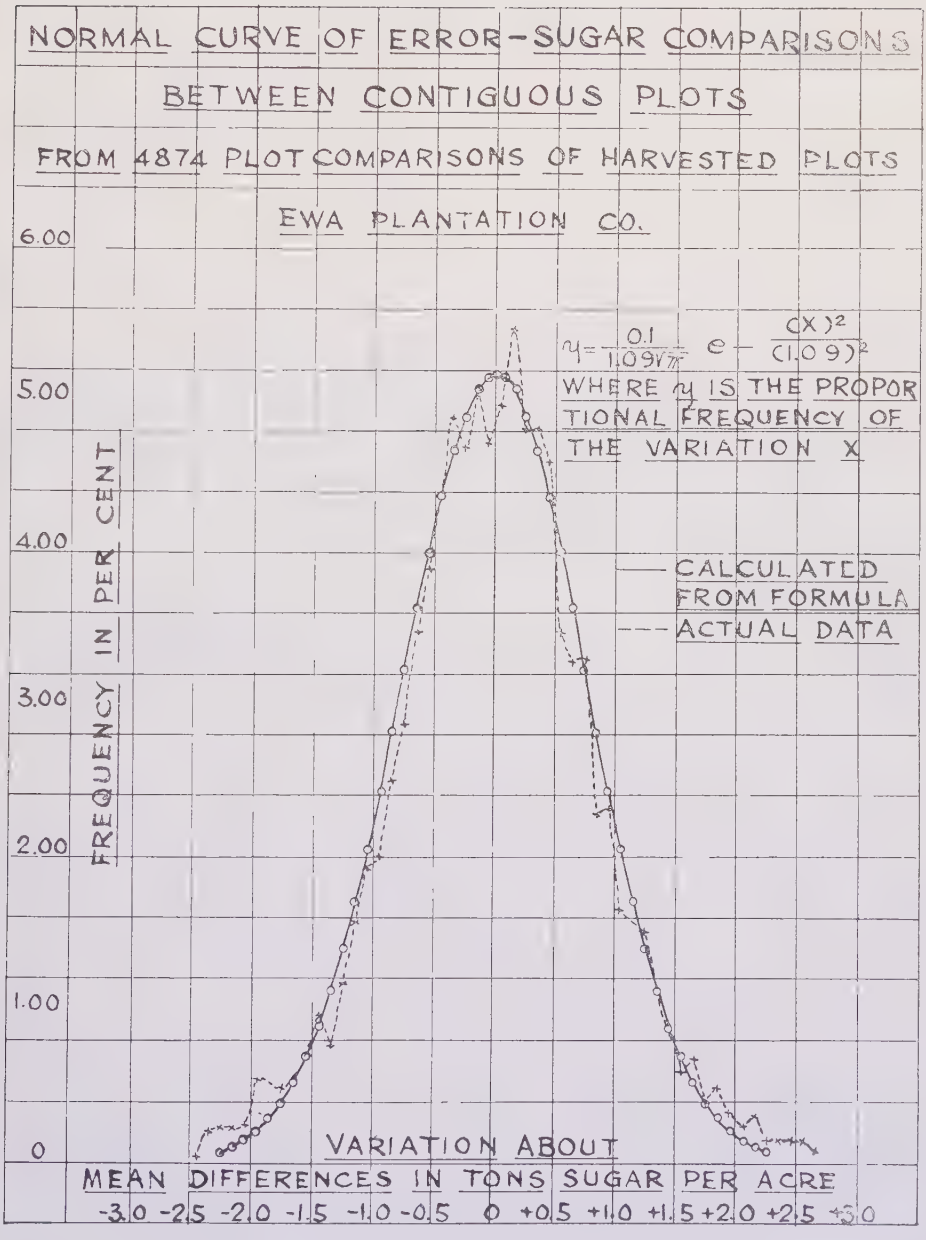

NORMAL CURVE OF ERROR-SUGAR COMPARISONS
BETWEEN CONTIGUOUS PLOTS
FROM 4874 PLOT COMPARISONS OF HARVESTED PLOTS
EWA PLANTATION CO.
$y = \frac{0.1}{1.09\sqrt{\pi}} e^{-\frac{(X)^2}{(1.09)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
FREQUENCY IN PER CENT
6.00
5.00
4.00
3.00
2.00
1.00
0
VARIATION ABOUT
MEAN DIFFERENCES IN TONS SUGAR PER ACRE
-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0 +0.5 +1.0 +1.5 +2.0 +2.5 +3.0

Fig. 8

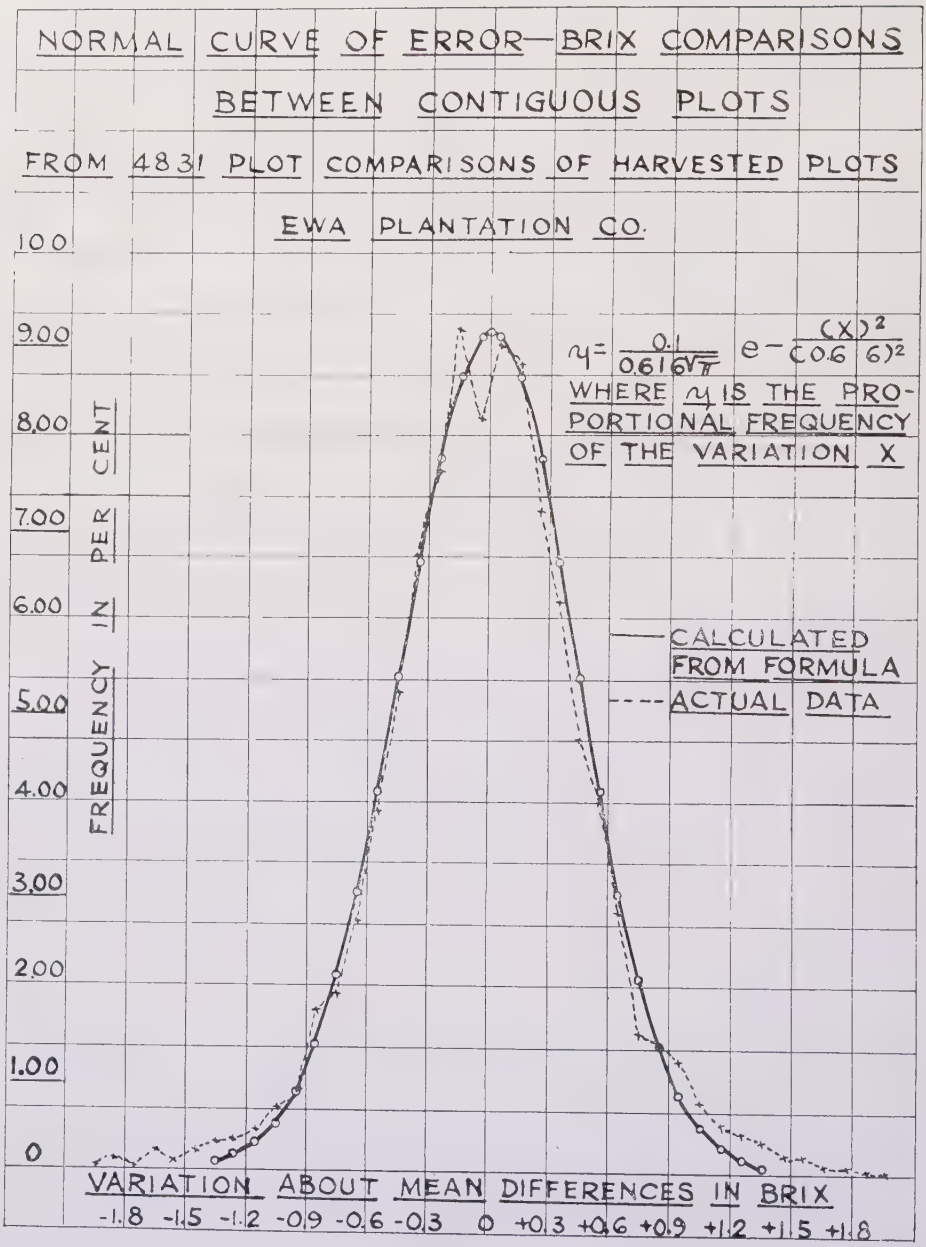

NORMAL CURVE OF ERROR—BRIX COMPARISONS
BETWEEN CONTIGUOUS PLOTS
FROM 4831 PLOT COMPARISONS OF HARVESTED PLOTS
EWA PLANTATION CO.
100
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0
FREQUENCY IN PER CENT
$y = \frac{0.1}{0.616\sqrt{\pi}} e^{-\frac{(X)^2}{(0.6\ 6)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
VARIATION ABOUT MEAN DIFFERENCES IN BRIX
-1.8 -1.5 -1.2 -0.9 -0.6 -0.3 0 +0.3 +0.6 +0.9 +1.2 +1.5 +1.8

Fig. 9

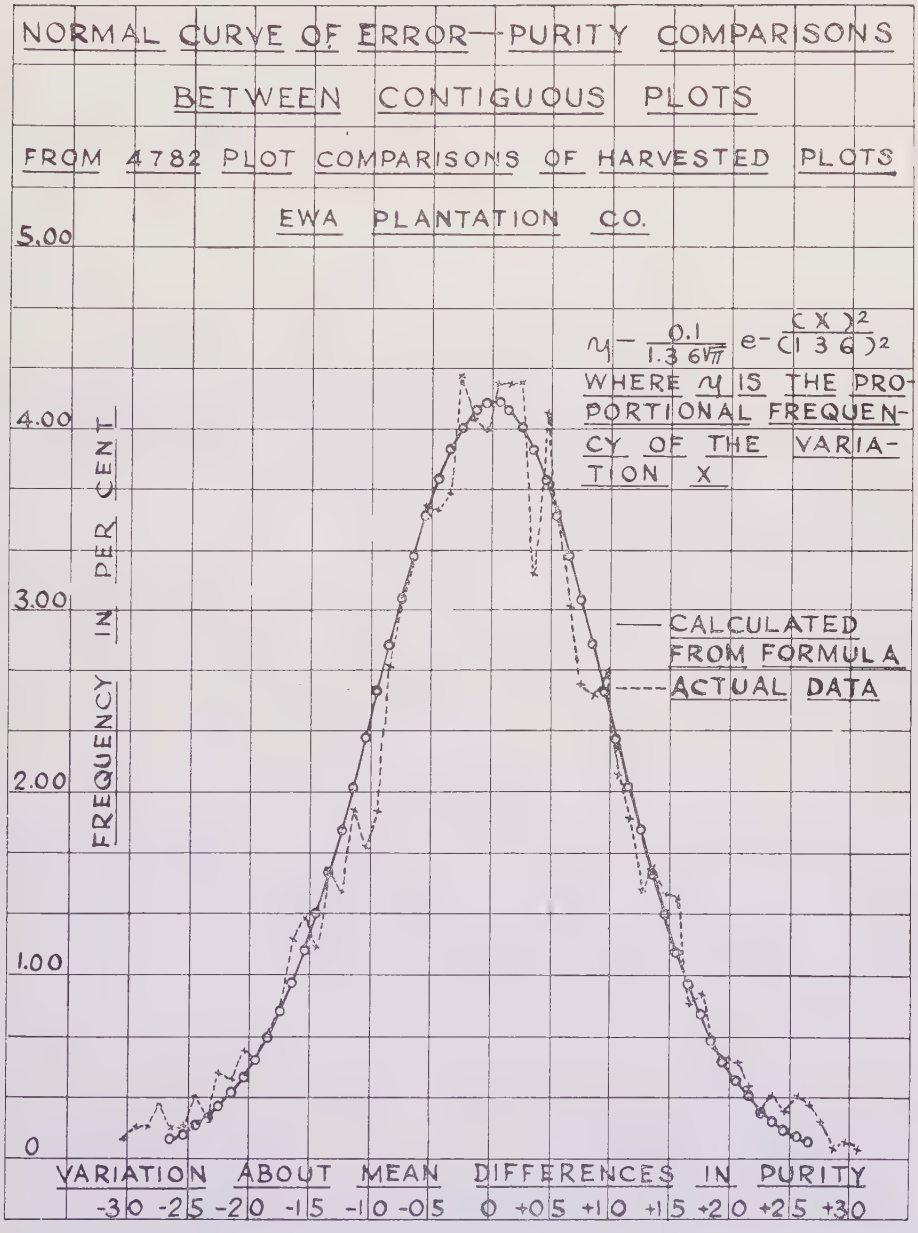

NORMAL CURVE OF ERROR—PURITY COMPARISONS
BETWEEN CONTIGUOUS PLOTS
FROM 4782 PLOT COMPARISONS OF HARVESTED PLOTS
EWA PLANTATION CO.
5.00
4.00
3.00
2.00
1.00
0
FREQUENCY IN PER CENT
$y = \frac{0.1}{1.36\sqrt{\pi}} e^{-\frac{(X)^2}{(1.36)^2}}$
WHERE y IS THE PROPORTIONAL FREQUENCY OF THE VARIATION X
CALCULATED FROM FORMULA
ACTUAL DATA
VARIATION ABOUT MEAN DIFFERENCES IN PURITY
-3.0 -2.5 -2.0 -1.5 -1.0 -0.5 0 +0.5 +1.0 +1.5 +2.0 +2.5 +3.0

Fig. 10

Sugar Prices

96° Centrifugals for the Period June 16 to Sept. 15, 1930

Date	Per Pound	Per Ton	Remarks
June 16, 1930	3.335¢	$66.70	Cubas, 3.33, 3.34; Philippines, 3.33.
" 17	3.285	65.70	Cubas, 3.27; Porto Ricos, 3.30.
" 18	3.2533	65.07	Cubas, 3.24; Philippines, 3.25, 3.27; Porto Ricos, 3.27.
" 20	3.24	64.80	Cubas.
" 24	3.255	65.10	Philippines, 3.24; Porto Ricos, 3.27.
" 25	3.285	65.70	Cubas, 3.27, 3.30.
" 26	3.30	66.00	Cubas; Porto Ricos; Philippines.
" 27	3.38	67.60	Cubas, 3.35, 3.41; Philippines, 3.35, 3.38.
" 30	3.355	67.10	Cubas, 3.38; Porto Ricos, 3.33.
July 2	3.31	66.20	Cubas, 3.32; Philippines, 3.30.
" 7	3.30	66.00	Porto Ricos.
" 8	3.2833	65.67	Cubas, 3.27, 3.28; Philippines, 3.28, 3.30.
" 10	3.3167	66.33	Cubas, 3.32, 3.33; Philippines, 3.30; Porto Ricos, 3.30, 3.32.
" 11	3.3075	66.15	Cubas, 3.28, 3.32, 3.33; Porto Ricos, 3.30.
" 14	3.275	65.50	Cubas, 3.27, 3.28; Philippines, 3.28.
" 15	3.26	65.20	Cubas.
" 16	3.25	65.00	Cubas, 3.25, 3.26; Philippines, 3.24.
" 18	3.26	65.20	Cubas.
" 22	3.28	65.60	Cubas; Philippines.
" 24	3.255	65.10	Cubas; Porto Ricos.
" 25	3.25	65.00	Cubas.
" 28	3.22	64.40	Philippines.
" 29	3.195	63.90	Cubas, 3.20; Philippines, 3.19.
" 30	3.18	63.60	Cubas.
" 31	3.20	64.00	Cubas; St. Croix.
Aug. 5	3.205	64.10	Porto Ricos, 3.21; Philippines, 3.20.
" 7	3.2267	64.53	Cubas, 3.23, 3.25; Philippines, 3.20.
" 8	3.20	64.00	Cubas.
" 11	3.18	63.60	Cubas.
" 12	3.16	63.20	Philippines.
" 14	3.18	63.60	Porto Ricos; Philippines.
" 18	3.17	63.40	Cubas, 3.18; Philippines, 3.16.
" 19	3.16	63.20	Cubas; Philippines.
" 22	3.12	62.40	Philippines.
" 25	3.1233	62.47	Cubas, 3.12, 3.14; Philippines, 3.11, 3.12.
" 27	3.18	63.60	Cubas; Porto Ricos.
" 28	3.20	64.00	Cubas, 3.22; Philippines, 3.18; Porto Ricos, 3.18, 3.22.
Sept. 2	3.175	63.50	Philippines, 3.17, 3.18.
" 3	3.17	63.40	Porto Ricos, 3.16, 3.18.
" 4	3.15	63.00	Cubas.
" 5	3.155	63.10	Cubas, 3.15, 3.16.
" 8	3.15	63.00	Cubas.
" 9	3.135	62.70	Cubas, 3.14; Philippines, 3.13.
" 10	3.13	62.60	Cubas; Philippines.
" 11	3.14	62.80	Cubas.
" 12	3.15	63.00	Philippines.
" 15	3.14	62.80	Cubas; Porto Ricos, 3.15; Philippines, 3.13.

INDEX TO VOLUME XXXIV

An asterisk preceding a page number indicates that the subject is illustrated.

A

Page

Agee, H. P., Egyptian views ..... * 139
Formosan views ..... * 6
open letter to sugar technologists .. 417
Parshall measuring flume 5
Airplane sowing of tree seed ..... * 247
Annual synopsis mill data—1929 221
Asphaltic sealing of reservoirs ..... * 49
Ayres, Arthur, boric acid absorption of Kjeldahl nitrogen 313
cane growth studies at Waipio ..... * 445

B

Baits, rat poison 421
Barnum, C. C., brown stripe disease, susceptibility of canes to 117
carbohydrates in water-logged soils, decomposition of 329
eye spot disease, susceptibility of canes to 117
rat control in Hawaii 421
Biological effect of molasses in soils * 83, * 301
Bond, J. D., pre-harvest sampling of cane by refractometer at Ewa Pltn. Co... * 331
statistical data for interpretation of field experiments ..... * 477
Borden, Ralph J., replication of plot treatments 151
probable error of single plot tests with sugar cane ..... * 467
Borers, rice, and parasites 25
Boric acid absorption by Kjeldahl nitrogen 313
Breeding canes in the Philippines ..... * 409
Brodie, Hugh, methods in plant physiology * 247
Brown stripe disease, see diseases.

C

Cane—
annual synopsis of mill data—1929 .. 221
breeding, in Formosa ..... * 11
in the Philippines ..... * 409
damaged by rats 421
diseases, see diseases.
experiments, see experimnts.
fertilization, see fertilizer.
growing, in Egypt ..... * 139
in Formosa .....* 7, * 8, * 9, * 11
in the Philippines ..... * 403
growth, in tap water ..... * 247
root development ..... * 99
studies at Waipio ..... * 445
winter ..... * 393
irrigation, see irrigation.
Java varieties, see varieties.
juices, see juices.
plant physiology ..... * 247
pollen, germination ..... * 351
roots, development ..... * 99
nematode attack ..... * 379
tissue fluids in relation to drought-resistance 167
varieties, see varieties.
Cane-killing weed 263
Carbohydrates, decomposition of in water-logged soils 329
Carpenter, C. W., notes on pythium root rot ..... * 83
Cassidy, Gertrude, nematodes associated with sugar cane in Hawaii ..... * 379
Chlorosis, see diseases.
Chlorotic streak disease, see diseases.
Colorimetric method for phosphorous determinations 307

D

Page

D 1135, see varieties.
Das, U. K, wilting coefficient of selected Waipio soil ..... * 289
Diseases of cane—
cane-killing weed 263
chlorosis ..... * 17, * 79
chlorotic streak disease ..... * 375
eye spot 263
gumming disease ..... * 65, 263
leaf scald 263
Pahala blight ..... * 17
pineapple disease 263
pokkah boeng 263
red rot 263
root rot ..... * 83, 263
smut 263
stem deterioration 263
streak disease 263
Ditch lining ..... * 49
Doty, R. E., iron sulphate spray for coral chlorosis ..... * 79
Drainage of Ewa Pltn. Co. soils ..... * 179

E

Egypt, Java canes growing in ..... * 139
Egyptian views ..... * 139
Entomology—
see rice borer.
Ewa Pltn. Co., iron sulphate spray for coral chlorosis ..... * 79
irrigation and drainage of soils .... * 179
pre-harvest sampling of cane by refractometer ..... * 331
statistical data for interpretation of field experiments ..... * 477
Experiments—
cane—
growth, in tap water ..... * 247
studies at Waipio ..... * 445
winter ..... * 393
juice, pre-harvest sampling .... * 331
leaf tissue fluids in relation to drought resistance 167
pollen, germination ..... * 351
rat damaged 421
root development ..... * 99
chlorosis, Hawaiian Agr. Co. ..... * 17
iron sulphate spray for ..... * 79
drainage, Ewa Pltn. Co. ..... * 179
fertilizer, molasses ....* 33, * 83, * 301
lysimeter ..... * 157
plots, probable error of single tests * 467
treatment 151
root rot ..... * 83
soils, molasses in relation to microbiological activity in ..... * 301
statistical data, interpretation ..... * 477
Eye spot disease, see diseases.

F

Fertilizer—
bagasse ..... * 83
effect on chlorosis ..... * 17
on cane growth ..... * 445
on root rot disease ..... * 83
molasses .....* 33, * 83, * 301
mudpress ..... * 83
stable manure ..... * 83
Ficus plantings ..... * 267
Field experiments, see experiments.
Figs in Hawaiian forests ..... * 267
Flumes, water, see irrigation.
Forestry, in Formosa ..... * 317
on Oahu ..... * 267
Formosa, cane breeding in ..... * 11
cane varieties in ..... * 9
farmsteads ..... * 6, * 8
field laborers ..... * 7

Page

forestry ..... * 317
Java canes in ..... * 7, * 8, * 9
Formosa 4, see varieties.
Formosa 19, see varieties.

G

Germination of sugar cane pollen..... * 351
Growth of sugar cane.....* 247, * 393, * 445
Gumming disease, see diseases.

H

H 109, see varieties.
Hadden, Fred C., oriental rice borers and parasites 25
Hance, F. E., asphaltic sealing of reservoirs ..... * 49
lysimeter experiments, interpretation of results ..... * 157
Harris, J., Arthur, sugar cane tissue fluids in relation to drought resistance..... 167
Hartung, W. J., lysimeter experiments, interpretation of results..... * 157
Hawaiian Agricultural Co., soil treatment for chlorosis ..... * 17
Hawaiian-Philippine Co., cane varieties.. * 403
Heck, A. Floyd, relation of molasses to micro-biological activity in soil.... * 301
Honokaa Sugar Co., cane growth experiments ..... * 393
Hydrogen electrode, soil reaction determinations 461

I

Insects—
see rice borer.
International society of sugar cane technologists, open letter..... 417
Iron sulphate spray for coral chlorosis.. * 79
Irrigation—
Ewa Plantation Co. soils..... * 179
Parshall measuring flume..... 5, * 389
reservoirs, asphaltic sealing..... * 49
water measurement at Waipio..... * 389

J

Java canes, see varieties.
Jennings, W. C., winter cane growth at Kukuihaele ..... * 393
Juices, cane, sampling by refractometer * 331

K

Kjeldahl nitrogen, boric acid absorption 313
Kohala 107, see varieties.

L

Lahaina cane, see varieties.
Leaf scald, see diseases.
Lee, H. Atherton, sugar cane tissue fluids in relation to drought resistance.... 167
Lyon, H. L., methods in plant physiology * 247
Lysimeter experiments, interpretation of results ..... * 157

M

Mangelsdorf, A. J., cane breeding in Formosa ..... * 11
in the Philippines ..... * 409
cane varieties in Formosa..... * 9
in the Philippines ..... * 403
Martin, J. P., cane diseases in Mauritius 263
chlorotic streak disease..... * 375
forestry in Formosa..... * 317
gumming disease ..... * 65
Mauritius, cane diseases in..... 263

Page

McAllep, W. R., annual synopsis of mill data—1929 221
McCleery, W. L., annual synopsis of mill data—1929 221
McEldowney, Geo. A., forestry on Oahu * 267
McGeorge, W. T., Ewa Plantation Co. soils, irrigation and drainage..... * 179
molasses fertilization, effects on cane growth ..... * 33
Pahala blight ..... * 17
Measurement of water, see irrigation.
Micro-biological activity in soil, relation of molasses to ..... * 301
Mill data, annual synopsis, 1929..... 221
Molasses fertilization, effect on cane growth ..... * 33, * 83
micro-biological activity in soil..... * 301

N

Nematodes associated with sugar cane in Hawaii ..... * 379
Nitrogen, Kjeldahl, boric acid absorption 313

O

Oahu forestry ..... * 267
Olaa Sugar Co., chlorotic streak disease in P. O. J. 36 cane ..... * 375
Oriental rice borers and parasites..... 25

P

P. O. J. 36, see varieties.
P. O. J. 36M, see varieties.
P. O. J. 105, see varieties.
P. O. J. 161, see varieties.
P. O. J. 234, see varieties.
P. O. J. 979, see varieties.
P. O. J. 2714, see varieties.
P. O. J. 2725, see varieties.
P. O. J. 2727, see varieties.
P. O. J. 2878, see varieties.
Pahala blight, see diseases.
Parasites, rice borer..... 25
Parshall measuring flume..... 5, * 389
Pests of sugar cane—
nematodes ..... * 379
rats 421
Philippines, cane breeding in..... * 409
varieties in ..... * 403
Phosphorus determinations, colorimetric method for 307
Physiology of cane plant ..... * 247
Pineapple disease, see diseases.
Plant physiology, methods in ..... * 247
Plot treatments in field experiments.... 151
Poison bait for rats..... 421
Pokkah boeng, see diseases.
Pollen, sugar cane, germination in culture media ..... * 351
Pre-harvest sampling of cane juice by refractometer ..... * 331
Prices of sugar—
Sept. 19, 1929—Dec. 13, 1929.... 135
Dec. 16, 1929—Mar. 15, 1930..... 242
Mar. 17, 1930—June 13, 1930..... 369
June 16, 1930—Sept. 15, 1930.... 505
Probable error of single plot tests..... * 467
Pythium root rot, see diseases.

R

Rainfall in relation to cane growth at Kukuihaele ..... * 393
Rats, control in Hawaii..... 421
Red rot, see diseases.
Refractometer, pre-harvest juice sampling by ..... * 331
Reservoirs, asphaltic sealing..... * 49
Rice borer and parasites 25
Root rot, see diseases.
Roots, cane, development..... * 99

S

Page

Shaw, H. R., measurement of Waipio irrigation water ..... * 389
Smut, see diseases.
Soils—
carbohydrates in, decomposition of.. 329
hydrogen electrode, reaction..... 461
irrigation and dainage, Ewa Pltn. Co. * 179
molasses fertilization, effects of..*33, * 301
nematodes in ..... * 379
phosphorus determinations 307
root rot studies..... * 83
treatment for chlorosis ..... * 17
wilting coefficient, Waipio ..... * 289
Statistical data, study of and interpretation of field experiments.... * 467, * 477
Stem deterioration, see diseases.
Streak disease, see diseases.
Sugar—
cane, see cane.
prices of 135, 242, 369, 505
Sulphate iron spray for coral chlorosis.. * 79
Synopsis of mill data—1929..... 221

T

Tap water, growth of cane in..... * 247
Technologists' international society, open letter 417
Thallium sulphate, poison bait for rats.. 421
Tissue fluids of sugar cane in relation to drought resistance 167
Trees, see forestry.

V

Varieties of sugar cane—
annual synopsis of mill data—1929 221
breeding in the Philippines..... * 409
D 1135, chlorotic streak disease.... * 375
disease susceptibility, eye spot and brown stripe diseases..... 117
Ewa varieties, disease susceptibility 117
Formosa 4, in Formosa ..... * 9, * 11
Formosa 19, in Formosa..... * 9, * 11
H 109, growth in water culture.... * 247
root rot ..... * 83
H varieties, miscellaneous, disease susceptibility 117
Java varieties, disease susceptibility 117
growing in Egypt ..... * 139
Kohala 107, chlorotic streak disease * 375
Lahaina, root rot disease..... * 83
Manoa varieties, disease susceptibility 117
Miscellaneous varieties, disease susceptibility 117
P. O. J. 36, acreage census..... 149
chlorotic streak disease..... * 375
growing in Formosa ..... * 9
P. O. J. 36M, chlorotic streak disease * 375
P. O. J. 105, in Formosa..... * 9, * 11
P. O. J. 161, in Formosa..* 8, * 9, * 11
P. O. J. 234, chlorotic streak disease * 375
P. O. J. 979, chlorotic streak disease * 375
P. O. J. 2714, in Formosa.....* 9, * 11
P. O. J. 2727, in Formosa..... * 9
P. O. J. 2878, in Formosa.....*7, * 11
in the Philippines..... * 403
Uba varieties, disease susceptibility 117
Waialua varieties, disease susceptibility 117
Wailuku varieties, disease susceptibility 117
Yellow Caledonia, chlorotic streak disease ..... * 375
Venturi flume 5

W

Wadsworth, H. A., wilting coefficient Waipio soils ..... * 289
Waipio soils, cane growth studies..... * 445
irrigation water measurement..... * 389
wilting coefficient..... * 289
Ward, Ritchie R., colorimetric method for phosphorus determinations..... 307
soil reaction determinations by hydrogen electrode 461
Water—
cane growth in ..... * 247
irrigation, see irrigation.
measurement, see irrigation.
reservoirs, asphaltic sealing..... * 49
Weller, D. M., cane root development from root primordia..... * 99
pollen studies ..... * 351
Winter growth of sugar cane..... * 393
Wilting coefficient of Waipio soils..... * 289

Y

Yellow Caledonia, see varieties.

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TABLE OF CONTENTS

Page

The Parshall Measuring Flume 5

Formosan Views 6

Cane Varieties in Formosa 9

Cane Breeding in Formosa 11

Pahala Blight II 17

Oriental Rice Borers and Their Parasites 25

Some Effects of Molasses Fertilization 33

Asphaltic Sealing of Reservoirs 49

Gumming Disease of Sugar Cane 65

Iron Sulphate Spray for Coral Chlorosis 79

Notes on Pythium Root Rot VI 83

A Comparative Study of the Development of Sugar Cane Roots from Root Primordia 99

Relative Resistance and Susceptibility of Hawaiian and Introduced Cane Varieties to Eye Spot and Brown Stripe Diseases 117

Sugar Prices 135

Egyptian Views 139

P. O. J. 36 149

Replication of Plot Treatments in Field Experiments 151

An Interpretation of Results of Lysimeter Experiments of Twenty Years Ago in the Light of Present-Day Knowledge on Base Exchange 157

The Properties of the Tissue Fluids of Sugar Cane in Their Possible Relation to Drought Resistance 167

The Chemical and Physical Properties of Ewa Plantation Soils as Influenced by Irrigation with Artesian Water, with Special Reference to Drainage 179

Annual Synopsis of Mill Data 221

Sugar Prices 242

Methods in Plant Physiology 247

Cane Diseases in Mauritius 263

Forestry on Oahu 267

Page

Some Observations on the Wilting Coefficient of a Selected Waipio Soil 289

The Relation of Molasses to the Micro-Biological Activity in Soil..... 301

A Rapid Colorimetric Method for Phosphorus Determinations..... 307

Boric Acid Absorption of Kjeldahl Nitrogen..... 313

Forestry in Formosa 317

The Decomposition of Carbohydrates in Water-Logged Soils, and the By-Products Remaining in the Soil..... 329

The Pre-Harvest Sampling of Cane by Refractometer at Ewa Plantation Company 331

Pollen Studies II..... 351

Sugar Prices 369

Chlorotic Streak Disease of Sugar Cane..... 375

Nematodes Associated with Sugar Cane in Hawaii..... 379

Measurement of Irrigation Water to Small Plots at the Waipio Substation 389

Winter Growth at Kukuihaele 393

Cane Varieties in the Philippines 403

Sugar Cane Breeding in the Philippines..... 409

An Open Letter to All Sugar Technologists..... 417

Rat Control in Hawaii 421

Cane Growth Studies at Waipio Substation..... 445

The Determination of Soil Reaction by Hydrogen Electrode..... 461

A Study of the Probable Error of a Single Plot from Field Tests With Sugar Cane in Hawaii..... 467

Some Basic Statistical Data for the Interpretation of Field Experiments at Ewa Plantation Company 477

Sugar Prices 505

ILLUSTRATIONS APPEARING ON THE COVERS OF VOLUME XXXIV

January

A harvesting scene in Formosa, showing P. O. J. 2725, the principal cane variety.

A stalk of cane, variety H 109, growing in the water culture described in this issue.